The Royal Aeronautical Society

(FOUNDED 1866)

with which is incorporated The Institution of Aeronautical Engineers

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PROCEEDINGS

SIXTH MEETING, SECOND HALF, 66TH SESSION

The 6th meeting of the 2nd half of the 66th Session was held at the Royal Society of Arts on Thursday, March 19th, 1931. Mr. C. R. Fairey (President) in the Chair.

THE PRESIDENT: The standard and thoroughness of German scientific research work had evoked the admiration of the entire world and it was not without significance that the great majority of distinguished foreigners who had lectured before the Society, particularly this Session, were of German nationality. That evening they were to have the privilege of hearing a lecture giving a review of the research work of the German Aeronautical Research Institute, and as the lecturer they had no less an authority than Dr. Hoff, the Principal of that Institute. It was impossible in a few words of introduction to do justice to so distinguished a career as that which Dr. Hoff had had, but it would be of interest to give a few details. As far back as 1910 Dr. Hoff was the designer of aeroplanes with the famous Major Von Parseval, who in those days was well known as a designer of airships and the constructor of a quite successful airship for those times. In 1911-12 Dr. Hoff was assistant to Professor Reiffner at Aachen, and in 1913 he joined the German Experimental Institute for air traffic, first as manager of the Aeroplane Department and then in 1920 as manager of the German Aeronautical Research Institute. During the war he was an officer in the German Flying Corps. Since 1923 Dr. Hoff had been Professor of Aeroplane Construction at the Technical High School in Berlin.

RESEARCH WORK OF THE "DVL"

BY

WILH. HOFF

In the later part of autumn last year, I was invited by your President, Colonel the Master of Sempill, to read a paper about the work of the "Deutsche Versuchsanstalt für Luftfahrt" (*i.e.* "German Aeronautical Research Institute").

The Royal Aeronautical Society can look back to a long and successful development. Your Society has always aimed at the promoting of the technical work of your country and at the fostering of close scientific relations between air-minded countries. It is therefore a great honour for me to lecture before your Society.

I regard co-operation in discussing aeronautical matters between the various countries as very necessary. Representatives of aeronautical science have, during the past year, held international congresses at Stockholm, in the Hague and finally in Paris. Common problems were treated at these congresses by the representatives. New personal relations were formed during the meetings held there. We had the opportunity of learning that the problems to be treated in the various countries are very similar to each other. Moreover, we observed

with satisfaction that the results obtained were helping one another. In Germany we always follow with great interest the publications of the English aeronautical research laboratories.

The opportunity to get in touch with your research institutions is one I much appreciate as a special advantage of my being here.

Your kind invitation renders it possible for me to deal with a range of work with which I am very much concerned. Nearly every aeronautically interested country has a central aeronautical research and testing institute. The organisation and structure of these chief aeronautical institutions are, of course, different in each country. The greater the number of independent research laboratories with specified interests in a country, the more has the central institution the possibility to restrict its work to collecting and administrating the results and research experiences of the different laboratories. Such collecting institutions work in touch with the aircraft industry and with the users of aircraft. These central institutions serve for the requirements of the industry and the users. Research laboratories with limited interests—in Germany essentially university institutions—are devoting their work usually to more general scientific problems. It is the duty of a central institution to answer mostly the urgent requests of the day. In Germany the " Deutsche Versuchsanstalt für Luftfahrt," or " DVL," incorporates the central aeronautical technical and scientific institution.

To-night I want to draw your attention to the range of work of the " DVL."

In the year of the foundation of the " DVL," in 1912, there already existed the aerodynamical laboratories of Göttingen and Aachen (Aix-la-Chapelle). The " DVL " was not founded then as a state institution, but as an institution supported by a legally formed association, the members of which were authorities, industrial firms and private persons. This enabled the " DVL " to develop freely, which would not have been possible in a state institution. The ownership of the " DVL," the legal association, is now a particular feature of the " DVL." As a consequence of our hard struggling aeronautical industry, the influence of the non-public members of the association is now by far inferior to the leading membership of the Reichsverkehrsminister (Minister of Communications). The Reichsverkehrsminister therefore possesses in the association particular rights of approvals. These rights extend both to the application of the allowance of the Reichsverkehrsminister and to the orders given by the latter to the " DVL."

In the first 12 years of its existence, the " DVL " suffered an often changing fate. After the re-establishment of our German valuta, and chiefly after loosening by international regulations some rules of the treaty of Versailles and of later restrictions forced upon our aerial navigation, the " DVL " was able to organise its modern sphere of work.

The " DVL's" range of work to-day includes two chief branches. The former and older province is the examination and licensing of the German aeronautical construction, *i.e.*, aircraft engines, etc. The "DVL" is now the examining institution of Germany for all aeronautical material. The " DVL " carries out this work as a mandate of the Reichsverkehrsminister, under the rules concerning the examination stated in the German Aerial Transport Law (" Luftverkehrsgesetz "). The work of the examination department (" Prüf-Abteilung ") includes the certifying of types, the examination of construction and design, built according to approved type certificates, and the later revision of licensed aeronautical construction and design.

During its first years, the " DVL " itself set up the necessary examination rules and proposed these rules for approval to the Reichsverkehrsminister. This procedure now has changed. For several months there has been in existence by order of the Reichsverkehrsminister, the "Deutsche Luftfahrzeug-Ausschuss" (German Aircraft Committee). This committee is formed of representatives of

the government, of the German Federal States, of the industry, of the users, of the insurance-companies, of the crews, of the examination department and of bodies of the science. The German Aircraft Committee is charged with the drawing up of examination and licensing regulations, namely the "Bau- und Prüfvorschriften für Flugzeuge, Luftschiffe, Motoren und anderes Luftfahrtgerät" (*i.e.*, Rules for construction and examination of aeroplanes, airships, engines and other aeronautical material). The Reichsverkehrsminister issues these rules after his approval. The "DVL" works, therefore, now as a German examination institution under the authority of the Reichsverkehrsminister, and examines according to regulations, which are drawn up by the German Aircraft Committee and made legal by the Reichsverkehrsminister.

The EXAMINATION DEPARTMENT of the "DVL" has not only a staff at Berlin-Adlershof, the home of the "DVL," but also in several other towns of Germany, where an aeronautical industry or aircraft users exist.

I do not intend to give you here, details about the working of the examination department. Colonel H. W. S. Outram, the director of the Aeronautical Inspection Department in your Air Ministry, has visited the "DVL" several times. We have had friendly and detailed discussions about our work with one another. These discussions led to cordial relations between the English and the German examination departments. In certain cases there exists a mutual acknowledgment of our examination work. Our negotiations culminated in the result that the technical ideas about aircraft examinations are in a very good agreement between England and Germany. The exchange of ideas thus begun will certainly in the future be the cause for a better agreement of the regulations between the two countries.

On the occasion of the aeroplane disaster at Meopham (Kent), in which Colonel Henderson and others met their deaths, the Accidents Investigation Sub-Committee of your Aeronautical Research Committee, examined the accident in a detailed manner for some months. In this impartial inquiry, the Sub-Committee investigated in co-operation with German authorities. We were only too glad to make our observations about the probable causes accessible to the English inquiring body. We were very interested in the opinions of the English committee in its final report. This final report gave us an opportunity to discuss in a detailed way the English deductions. We have promised the Aeronautical Research Committee to communicate to them our opinion as to this report. We are convinced that we can serve only in that way for the technical development in both countries.

Finally, I should like to mention that at present there are negotiations in my country for the purpose of combining the aeronautical examination department of the "DVL" with the "Germanischer Lloyd," which is internationally well known as an examination department for ships. It is then intended to divide the "Germanischer Lloyd" into a naval department and an aeronautical one.

The chief advantage of such an arrangement will certainly be the self government of the aeronautical examination department under supervision of the Reichsverkehrsminister. If the "Germanischer Lloyd" takes over the aeronautical examination department, this department will be installed in the immediate neighbourhood of the "DVL". The closest co-operation together with the other "DVL" departments will be guaranteed by certain binding agreements.

The other great sphere of work of the "DVL" is aerotechnical research. The "DVL" possesses a number of technical installations, laboratories and other research equipment, to carry out the tasks of these branches. The arrangement of the "DVL" is not uniform, owing to the fact that it was impossible to anticipate in 1912 the present extension of aeronautical science, and furthermore because buildings originally destined for other purposes had to be rebuilt for

laboratories. The Reichsverkehrsminister has been of the opinion for some time that the working conditions of the " DVL " are not good, and has insisted therefore upon a rebuilding of the " DVL," and also upon its equipment with all those technical installations which cannot with safety be placed in the existing buildings of the " DVL " in Berlin-Adlershof. The need for economy in Germany prevents construction of the new building for some time.

The different branches of research at the " DVL " are treated by seven research departments collaborating in close touch with one another. Each research department has a chief who is responsible for his range of work.

The names of the various research departments do not indicate the whole sphere of work belonging to each department. Full details are published in the " DVL " year books, and the ranges of work of each department are described there.

I believe it will be more interesting for you to-night, to treat for each research department some few important problems, on which we have been working successfully.

The head of the Aerodynamical Department is Dr. Ing. Friedrich Seewald, a pupil of Prof. Dr. v. Kàrmàn, Aachen. In aerodynamics, we follow the methods of other aerodynamical laboratories, especially those of Göttingen and Aachen. Unfortunately, the " DVL " does not yet possess a wind tunnel. In my country, we still have very few of these important aids to aerodynamical research.

The Aerodynamical Department undertook the full scale measurement of air forces on the aeroplane. The department developed for this task the necessary instruments. I shall describe one important instrument that has been developed.

The relative wind of flight attacks the wings according to the flight conditions The wing structure carries the air forces to the points where the loads of the aeroplane act in flight. The loads taken up by the structural members lengthen these members as a consequence of the working stresses. The elongations are a direct measure for the loads and stresses in the supporting structural members. Therefore the elongation in the structural members allows us to calculate the actual air forces.

Instruments for directly recording the elongations are used by us for obtaining data of the service loads of aeroplanes. In order to get a reliable recording light instrument, the elongation is directly scratched on glass by diamond tips at its full value and without any transmission or multiplication gears (Figs. 1-3).

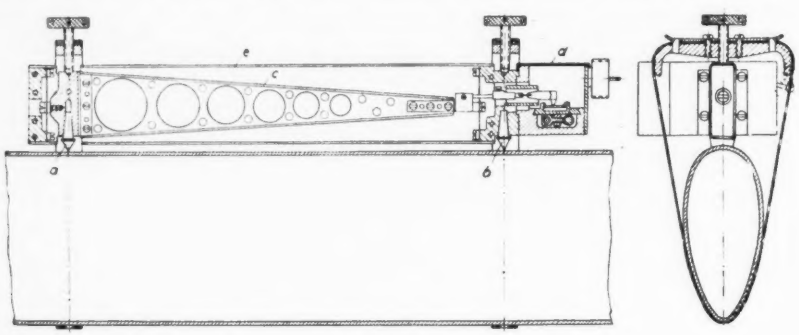

FIG. 1.

Scheme of the Elongation Recorder.

The movement of the edge *a* relative to the edge *b* is transmitted by girder *c* to the diamond *d*. The latter scratches the movement full scale with microscopically fine lines on a small glass plate which moves at right angles beneath.

During preliminary experiments, we succeeded in getting these scratch marks so clearly that we now prefer this way of recording to all other ones. For interpretation the microscopically small scratch marks are enlarged and measured (Fig. 4).

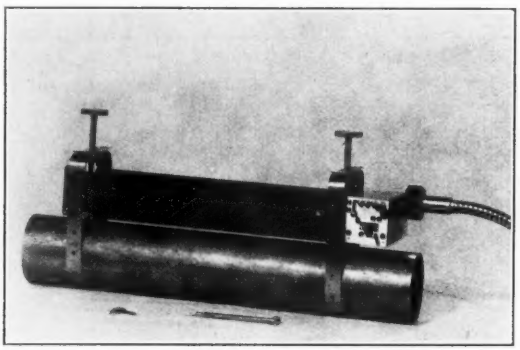

FIG. 2.

Photograph of the Elongation Recorder.

The instrument is mounted by steel strips on to a tubular strut.

As another example for the application of such an elongation recorder, Fig. 5 shows an instrument destined for recording occurring elongations in relation to time during a long flying time of the aircraft. This instrument is attached to the wing structure of the aeroplane. In this way we get the loads on those aeroplanes which meet frequently with bad weather during transport flights. We want thereby to collect data for the better understanding of the loads in normal air travel.

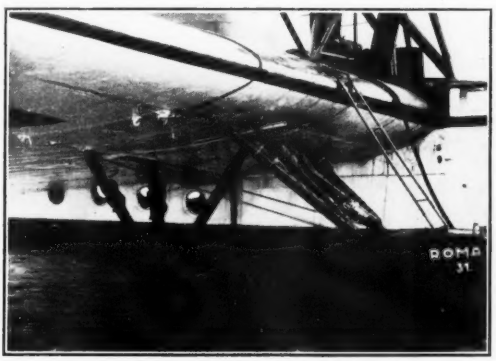

FIG. 3.

Mounting of the Elongation Recorder on the Streamlined Struts of the Lateral Supporting Float of a Flying Boat.

For protection against spraying water the instruments are packed in canvas, except the instrument nearest to bow. The common watertight enclosed electro-motor fixed to the struts directly over the float, drives the instruments through flexible shafts.

The Aerodynamic Department examines also the properties of floats and boat hulls of seaplanes. As the results of the tests with model floats towed in water tanks are insufficient for full scale results under real working conditions, tests with floats at full scale are necessary.

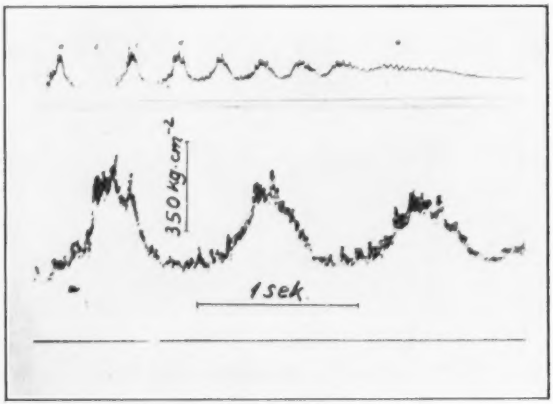

FIG. 4.

Tension Record of the Landing of a Flying Boat Measured at a Bulkhead with an Elongation Recorder.

a = First touching on the water.
b = Jump.
c = Second touching.
d = Porpoising of the flying boat, superseded by oscillations of the structure.
e = Coming to rest.
The record below is an enlarged part of motion *d*.

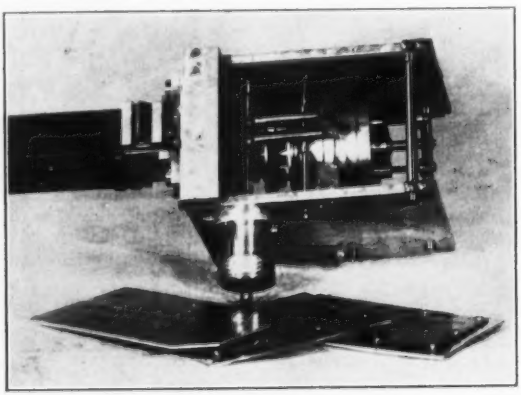

FIG. 5.

Long Time Recording Instrument.

This instrument serves for recording on a rotating drum, which at the same time moves in an axial direction. The registration length, after being enlarged 200 times, corresponds to a paper strip 200m. long.

A seaplane of medium size is equipped for this task as a flying laboratory for the testing of floats. A three component balance is mounted instead of the struts between one lateral float, fuselage, and wing. This balance renders it possible to measure the hydrodynamic forces on the float while testing under different speeds and trims (Figs. 6 and 7). The corresponding recordings of positions and speeds are made with instruments in the fuselage.

The preliminary tests with this installation are encouraging. We hope to get in this way principles for a logical design of floats and boat hulls.

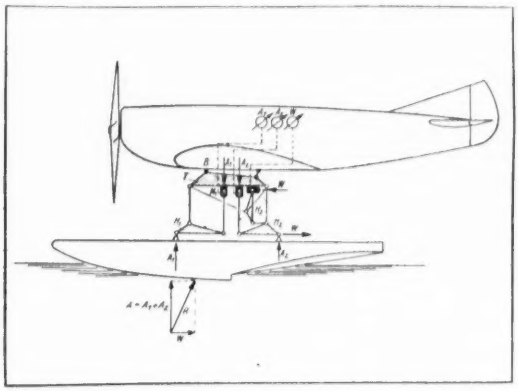

FIG. 6.

Three-Component Recording Instrument for Seaplane Floats.

The components A_1 and A_2 and W of the water force resultant are transmitted by the three levers H_1, H_2 and H_3 to the three dynamometer measuring cylinders M_1, M_2 and M_3. The measuring cylinders M_1 and M_2 take up the two load components A_1 and A_2, the cylinder M_3 the component of resistance W. The forces are transmitted by fluid pressure to the manometers in the observer's room. By turning the chief girder T around B the angle between float and plane structure, and thereby the angle of the wing can be changed.

FIG. 7.

The Experimental Aeroplane with the Three-Component Recording Instrument for the Test of Floats.

Resistance and trimming moment are measured at the port float.

Another sphere treated by the Aerodynamic Department is the research on airscrews. Calculations have shown that bending and torsion oscillations at the airscrew blades are to be expected under certain conditions in the service range of the propeller. We had to confirm the calculations by tests. For that purpose,

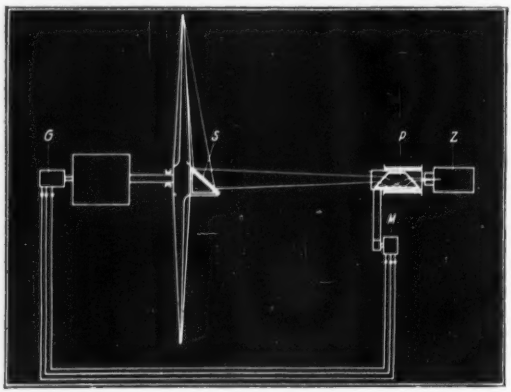

FIG. 8.

Scheme of the Arrangement for the Observation of Airscrew Oscillation.

The picture of the blade tip F is reflected by the mirror S rotating with the airscrew, and is observed by the rotating right-sighted prism P or recorded photographically with fast motion picture camera ("Time Retarder") Z. The prism produces a steady picture of the blade tip if rotating with half airscrew speed. Synchronisation between airscrew and prism is obtained by the generator G at the propeller shaft and by the synchron motor M (geared 2:1) which drives the prism.

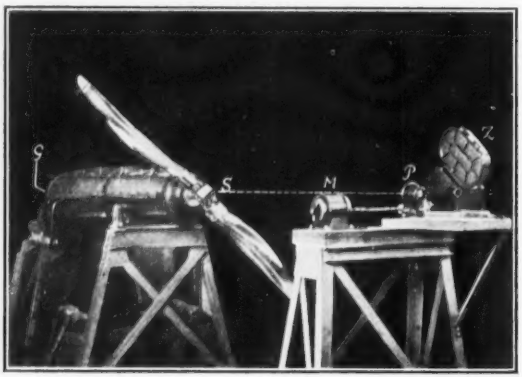

FIG. 9.

Experimental Installation for Observing Airscrew Oscillations.

G = Synchron generator on propeller shaft.
M = Synchron motor.
P = Right-sighted prism.
Z = Fast motion picture camera ("Time Retarder").
S = With airscrew rotating mirror.

simply treatable airscrew blades were designed, and their probable oscillating conditions calculated. This airscrew was now run on a propeller test stand with different speeds. An instrument mounted in front of the airscrew in direction of its axis makes the observation of propeller blade deflections possible by a steady rotation of a prism system (Figs. 8-10). The blade deflections are recorded by fast motion pictures (240 pictures per second; Figs. 11 and 12).

The STATIC DEPARTMENT (Stress Department), headed by Dr. Ing. Karl Thalau, is nowadays occupied with the dynamical loads on aeroplane structures.

As an example, I show you a wooden aeroplane wing spar which has a static load and also an oscillating bending load. We built an installation for testing

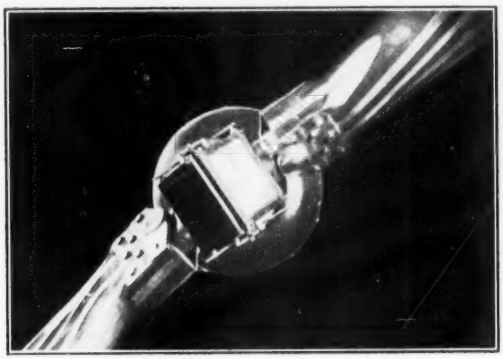

FIG. 10.

Two Mirrors fixed on Airscrew Hub.

In the right mirror can be seen the picture of one of the blade tips.

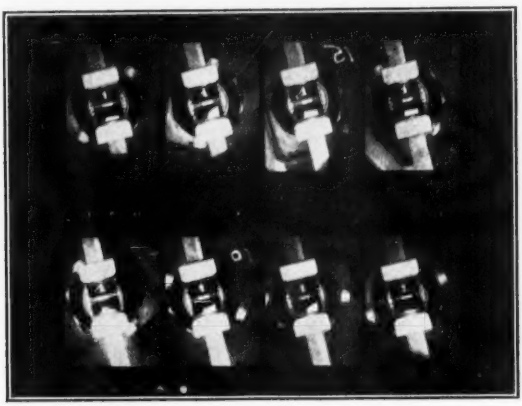

FIG. 11.

Part View from Fast Motion Pictures made with the "Time Retarder."

The rotating airscrew appears at rest, the background rotates. The blade tip of the oscillating model propeller is seen as a white trapezoid in the bottom mirror. Speed of photographing = 100 pictures per second.

the spar by the two load contributions, either combined or separated. The static load is suspended by rubber cords and in bags (Figs. 13 and 14). The spar is vibrated by a rotating unbalanced load (Fig. 15). The amplitudes of the oscillations result in additional stresses which add to the static strains.

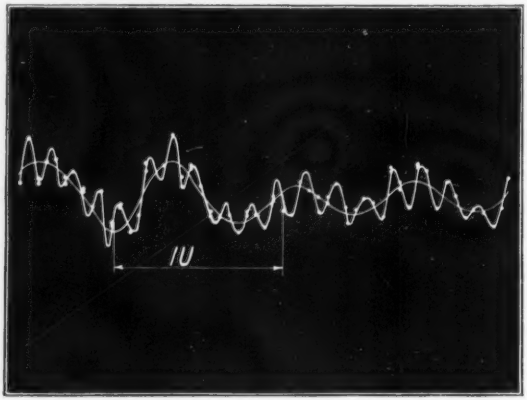

FIG. 12.

Oscillations of a Model Propeller.

Speed of rotation 400 r.p.m. (elaboration from fast motion pictures with about 130 pictures per second). The faster torsional oscillation supersedes the slow bending oscillation. The double arrow marks the duration of one turn. The measured frequencies are in a sufficient accord with the calculated values.

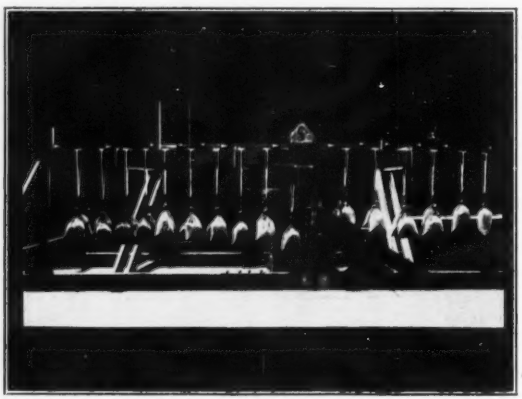

FIG. 13.

Oscillation Tests under Static Load of a Wooden Spar.

(*a*) Statically determinate bearing of the wooden spar in an anchored testing device; on the left pin jointed, on the right pendulum support.

(*b*) Static load by sand bags in a damped manner suspended by soft rubber cords from the ribs.

(*c*) Spar vibrations (resonance with the self-frequency) caused by the unbalancing load on the left from the pendulum support.

(*d*) Measurement of line of the amplitudes of the vibrating spar with optical amplitude measuring instruments on the spar flange (white triangle in black field).

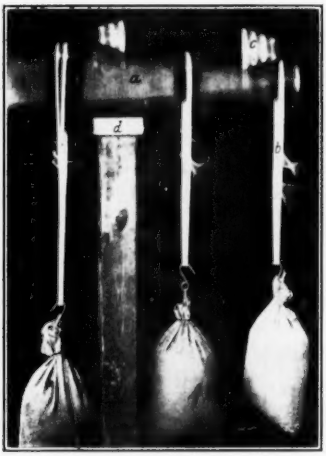

FIG. 14.

Oscillation Tests under Static Load of a Wooden Spar.

(*a*) The vibrating spar.
(*b*) Efficiency of the damped suspension of the static load by soft rubber cords.
(*c*) Manner of action of the optical amplitude measuring instruments. Overlapping of upper and lower extreme position of the white triangle; the shadow of the wedge shows at the vertical millimetre scale the size of the amplitude.
(*d*) Catching device for resulting breaking of the spar; vertical support.

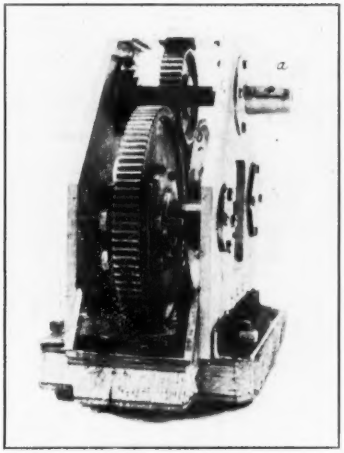

FIG. 15.

Double Unbalanced Load for the Creation of Oscillations.

(*a*) Drive by flexible shaft at the shaft pin (right above).
(*b*) Gearing by toothed wheels 1 : 2.
Arrangement of the interchangeable lead blocks visible at the front wheel.
(*c*) Controlling the great wheels in opposite rotating direction; only the vertical component of force is acting. Controlling the great wheels in the same rotating direction with lead blocks displaced by 180°; moment acting.

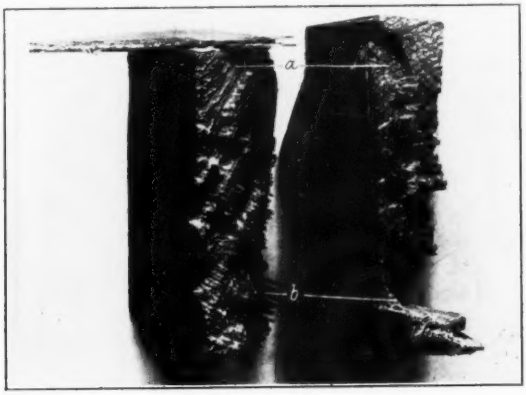

FIG. 16.

Oscillation Tests under Static Load of a Wooden Spar.

Broken section of the spar; material, spruce.
(*a*) On the left: smooth fatigue rupture with short fibres.
(*b*) On the right: static rupture with long fibres.

The amplitudes are optically measured by a simple method. From the deflections read the actual strains are in a simple calculated manner. A calculation of the stresses in the spar is also possible with the elongations recorded by the already described scratch recorders. The tested spar vibrates till a rupture occurs. From the appearance of the breaking section we arrive at an idea of the quality of construction of the aircraft part in question (Fig. 16).

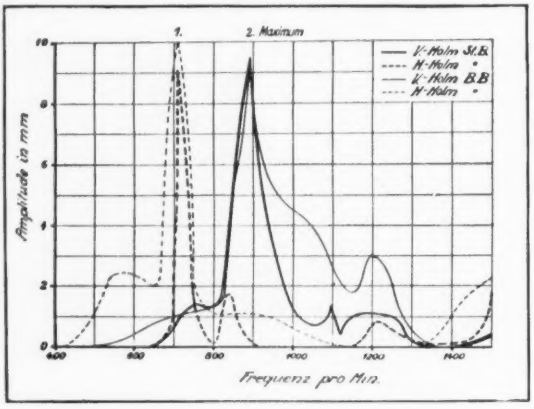

FIG. 17.

Curves of Resonances for an Aeroplane Wing.

Measured at the wing tips of front and rear spar, port and starboard.
1st. Maximum: near 710 oscillations per minute, self-oscillations of the rear spar.
2nd. Maximum: near 880 oscillations per minute, self-oscillations of the front spar.
The other peaks are influences of the structure parts coupled with the spars like floats, fuselage, tailplanes, etc.

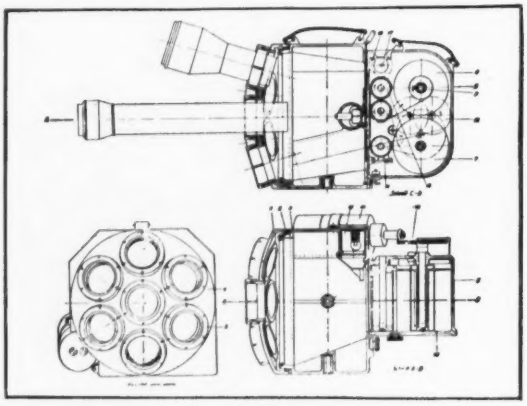

FIG. 18.

Sketch of the "Optograph."

Turnable head of objective 1 with objective rings in which the single objective lenses are inserted. In box 5 is a highly sensitive silver bromide film over three rolls running with constant speed. These rolls are driven by motor 14 with rubbing impulse gear 13 and gear 12. Synchronising marks and Morse signs are given by separated marking instrument with incandescent lamp 18.

Another investigation method has been developed by the Static Department for finding out undesired vibrations by suspension of the whole aeroplane. The production of resonances at different speeds of engine rotations by means of an unbalanced load is caused in the same manner as described above. These tests reveal peculiarities of vibration for the whole aeroplane (Fig. 17). We are able in that way to discover if the structure parts of an aeroplane show self-oscillations in the range of normal engine speeds.

The Static Department investigates also the analytical methods of wing stress calculation. It is important to confirm the results of these calculations in the practical case. For that purpose we develop a particular instrument called the "Optograph." This instrument makes it possible to record the deflections of whole structure parts. The Optograph consists of a camera with several photographic objectives (Fig. 18). The camera is mounted at a suitable place in the fuselage (Fig. 20). Light points on the structure parts to be examined are

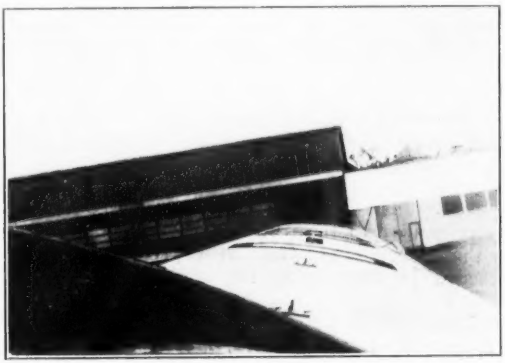

FIG. 19.

Arrangement of Marking Lamps on a Wing.

Incandescent lamps with short thread are installed along a spar (near to the neutral axis).

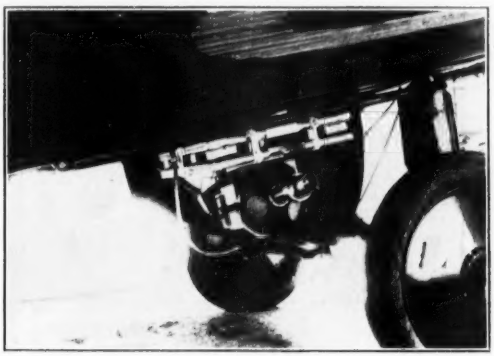

FIG. 20.

Optograph mounted under a Fuselage.

For the observation of wing deflections from below.

photographically recorded (Figs. 19 and 21). The motions of these points show the deflections of the structure parts.

We can also replace the light points by a lamp fixed at each objective, the light of which will be reflected by a triple-mirror. The various triple-mirrors are fixed at the place to be measured.

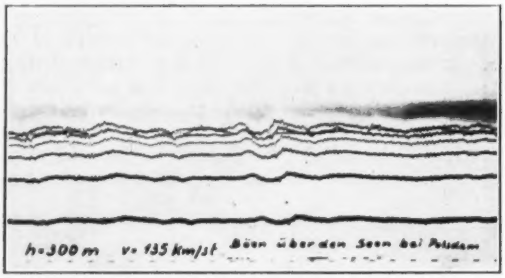

FIG. 21.

Record of a Trial Flight with the "Optograph."

The light points marked over the wing spar show deflections effected by the wing load. Gusts during bad weather cause heavy stresses.

The Static Department is also working on construction problems. As an example, I may refer here to the wheel brakes developed in the DVL following a suggestion by the Association of German Airport Societies. These wheel brakes have now succeeded in overcoming the objection with regard to the weight (Fig. 22).

The ENGINE DEPARTMENT, for the moment temporarily in charge of Dipl.-Ing. O. Kurtz, has to investigate all research problems of the power plant. Engines are not so accessible to scientific research as the aeroplane itself. Engines are developed usually as the result of practical experience. Theoretical knowledge

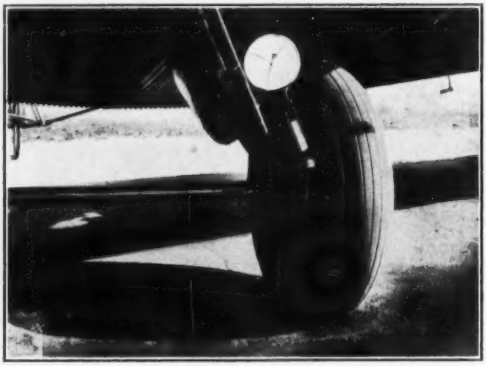

FIG. 22.

Electron Aeroplane Wheel with Brakes mounted on a large Aeroplane.

The transmitting rod for the brake torque moment is replaced by a dynamometer, the pointer of which can be observed by means of a mirror in the cabin. The reading serves to get a rough estimate of the *average* braking moment occurring in braking.

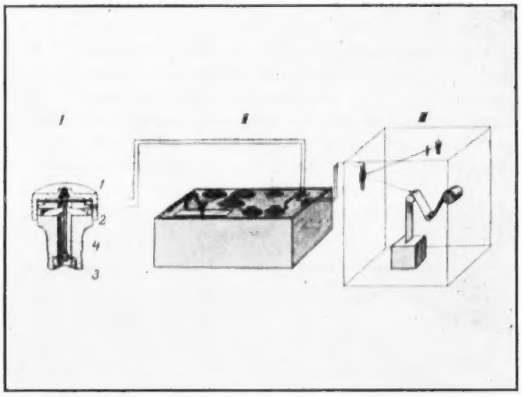

FIG. 23.

Measuring Device for Rapid Pressure Changes.

I. ***Transmitting instrument.***—Self-frequency 3,000 Hertz. The pressure to be measured changes the capacity of a condenser.

1 = Movable condenser plate.
2 = Fixed condenser counterplate.
3 = Auxiliary membrane for keeping off the burning gases.
4 = Transmitting pin.

II. ***Control instrument.***—The capacity changes of I. are transferred by two high frequency circuits tuned with another and by a redressing tube in the control instrument II. into current changes.

III. ***Oscillograph record.***—The current changes produced by instrument II. are photographed by the oscillograph.

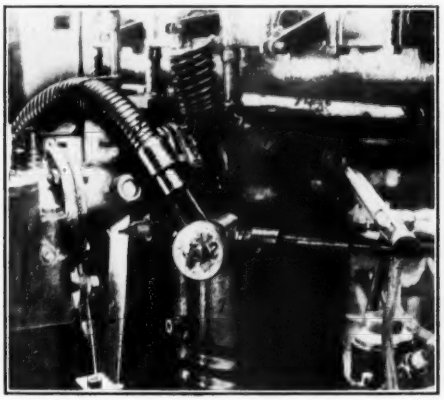

FIG. 24.

Transmitting Instrument mounted on an Aeroplane Engine Cylinder for Pressure Recording.

1. Aircraft engine cylinder.
2. Transmitting instrument.
3. Electrical connection lead with metal braided tubing to prevent changes of capacity.

penetrates slower into engine construction than is usually the case with aeroplane construction.

As a first example of our scientific work on engines, I will describe to you how we succeeded in getting indicator diagrams from high speed engines. A record free from distortion of the pressure due to time in the engine cylinders is of paramount importance for the accurate examination of combustion phenomena. Our new method is based on the operating of a pressure transmitter upon a condenser, whose changes of capacity can be altered by suitable high frequency controlling into current changes. These changes are recorded continuously by an oscillograph (Figs. 23-27).

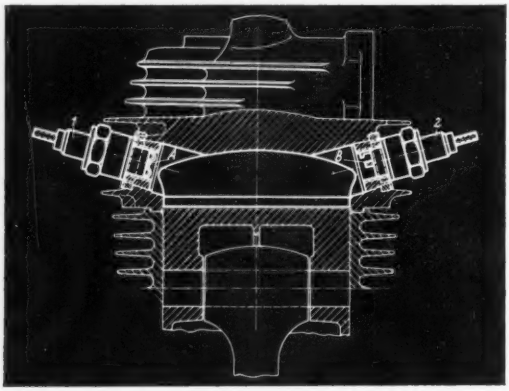

FIG. 25.

Measuring the Rate of Combustion of Spark Ignition Engines.
1 = Sparking plug. Starting of combustion (mark A).
2 = Sparking plug. Ionised spark gap which marks the coming of flame (mark B).
The time which is needed for the flame to advance from A to B is measured by oscillograph.

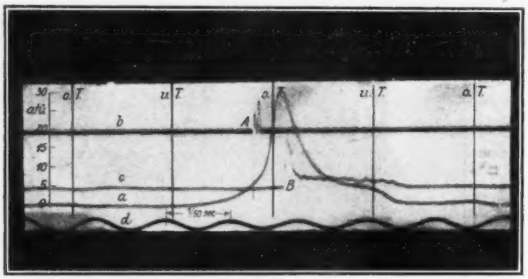

FIG. 26.

Performance due to Time of Occurrences in an Aircraft Engine Cylinder.

a = Line of pressure due to time.
b = Line of sparking voltage (mark A point of ignition).
c = Line for measuring the rate of combustion (mark B the flame reaches sparking plug 2).
d = Time marking.

A particular field of theoretical investigations of the Engine Department is the calculation of engines with regard to vibrations. As the torsional oscillations of the crankshaft are of particular importance, we built for this a Torsiograph (Figs. 28 and 29). This instrument is fixed on the rear end of the crankshaft and records the vibrations of the crankshaft. It is thereby possible to confirm the calculations by measuring the torsional vibrations.

The amplitudes of the oscillations are directly scratched on a celluloid film (Fig. 30). This film passes slowly over a pen. This recording method resembles the method used by the Cambridge Instrument Company.

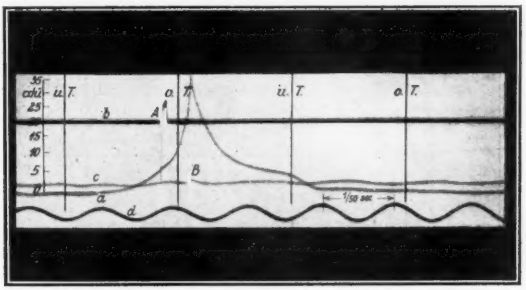

FIG. 27.

Performance due to Time of Occurrences in an Aircraft Engine Cylinder Running with Knocking Fuels.

a = Line of pressure due to time. Very violent increase of pressure at the moment of impact of knocking.

b = Line of sparking voltage (mark A point of ignition).

c = Line for measuring the rate of combustion (mark B the flame reaches sparking plug 2).

d = Time marking.

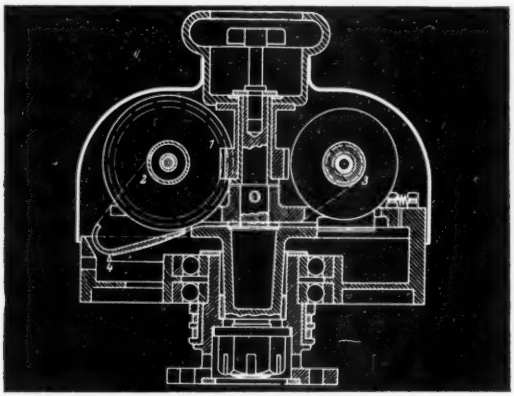

FIG. 28.

Torsiograph with Scratch Record (Scheme).

Steady rotating mass which carries the writing pin, part 1.

Mass flanged at engine's end which carries the celluloid film with leading drum, part 2, and trailing drum, part 3.

Control gear for starting the film. It serves also as a protecting cap. Part 4 is the worm with the worm wheel for the control of the film.

The " DVL " has succeeded in confirming on a number of occasions analytical calculations of vibrations on crankshafts by experimental tests.

The " DVL " is beginning researches on single-cylinder test engines (Fig. 31). Up to the present we have been able to put up only a few single-cylinder test engines for obtaining experience for the construction of multi-cylinder engines.

The MATERIAL DEPARTMENT, headed by Dr. Ing. Paul Albert Brenner, has to test materials used in aircraft construction for their quality and to investigate how to improve their qualitites.

As the shape of a structure part is often of great importance in its actual use, we carry out tests on these lines.

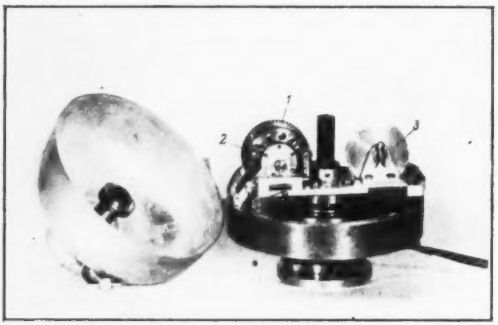

FIG. 29.

Side Elevation of the Torsiograph with Scratch Record, Protecting Cap Removed.

1 = Driving worm wheel.
2 = Leading film drum.
3 = Trailing film drum.

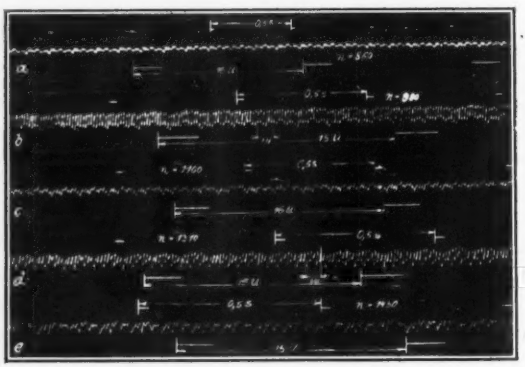

FIG. 30.

Torsiograms taken at a 6-cylinders-in-line Engine (250 PS).

(*a*) Below the critical speed of 6th order ($n = 860$ r.p.m.).
(*b*) In the critical speed of 6th order ($n = n_e/6 = 980$ r.p.m.).
(*c*) Between the critical speeds of 6th and 4, 5th order ($n = 1{,}110$ r.p.m.).
(*d*) In the critical speed of 4, 5th order ($n = n_e/4$, $5 = 1{,}310$ r.p.m.).
(*e*) Above the critical speed of 4, 5th order ($n = 1{,}430$ r.p.m.).

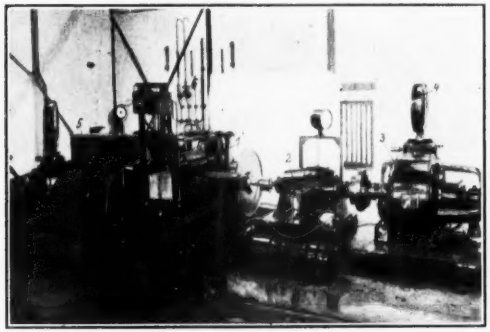

FIG. 31.

Large Single-Cylinder Test Bed of the "DVL."

On this universal test bed can be installed all types of cylinders up to 260 mm. bore and 310 mm. stroke. During the run we can change individually the compression ratio and timings. The measurement of power is made by pendulum dynamo with fixed toledo balance added.

1 = Single-cylinder test bed.
2 and 3 = Two pendulum dynamos.
4 = Toledo balance.
5 = Control desk.
6 = Device for measuring fuel consumption.

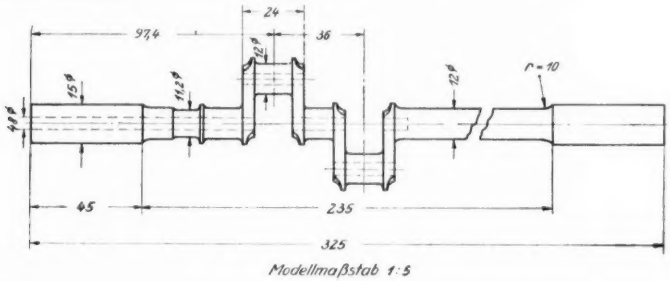

FIG. 32.

Model Crankshaft for Test under Torsional Vibration.

Dimensions of two-cranked model of an aircraft engine crankshaft. Model size, 1 : 5.

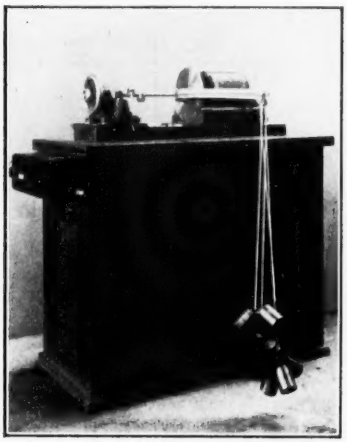

FIG. 33.

Torsional Vibration Tests with Model Crankshaft.

Installation of a model crankshaft into the MAN-torsional vibration testing machine.

Weights hanging from long rubber cords cause, by means of a light alloy lever, a static torque on the model crankshaft. The cords hang steady during the movement of the lever. Such static loads during torsional tests permit of measuring the torsional strength while putting on strains between negative and positive stresses.

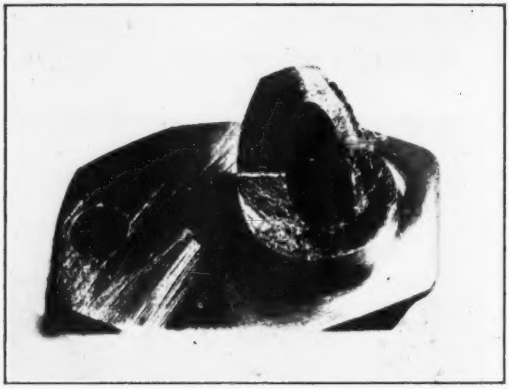

FIG. 34.

Breaking Section of a Model Crankshaft.

Breaking section of a model: spirally breaking through the crank pin.
The breaking begins at the opening of the oil hole and goes into the long bore of the crank pin.

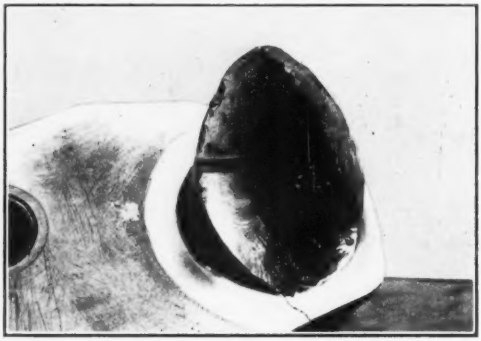

FIG. 35.

Breaking Section of an Aircraft Engine Crankshaft.

Breaking section of a ruptured crankshaft of an aircraft engine.
A comparison with Fig. 34 shows that the breaking of the model has taken place in exactly the same manner as the breaking of the crankshaft in flight.

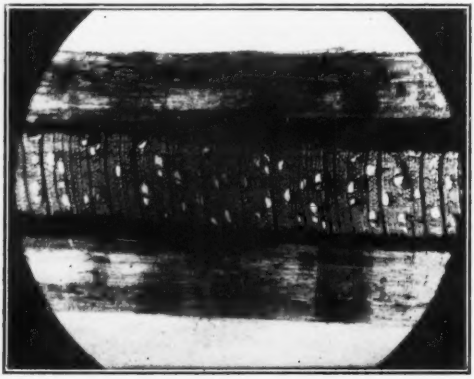

FIG. 36.

Aircraft Plywood Glued with Blood Albumin.

Microtomic section (1/50 mm.) through birch plywood glued with blood albumin (usual plywood glueing). The distribution of the glue layer is not uniform. $V = 50x$.

In past years, several ruptures of crankshafts have occurred. We were asked how the shape of crankshafts could prevent these breaks. We discovered a certain investigation method of great usefulness. The crankshaft to be considered was very carefully copied in size, 1 : 5, and stressed under torsional vibration effected by a simple testing device (Figs. 32 and 33). We succeeded in getting in this model crankshaft the same breaking peculiarities as were found in the shafts of full size (Figs. 34 and 35).

In Germany we often use plywood in aircraft construction. The plywood is glued with blood albumin (Fig. 36). The glueing up is not at all reliable. Recently in Germany there has been made a plywood glued by inserting foils of artificial resin between the veneers (Fig. 37). This results in a much better binding of the veneers together. Strength tests show a much better and more intimate binding with the new method (Figs. 38 and 39).

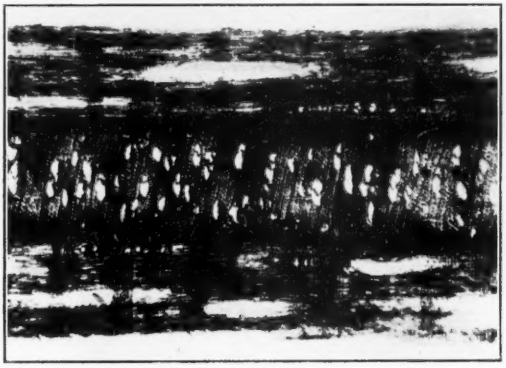

FIG. 37.

Aircraft Plywood Glued with Artificial Resin Foil.

Microtomic section (1/50 mm.) through birch plywood glued with double artificial resin foils (new plywood glueing). The distribution of the glue layer is uniform. $V=50x$.

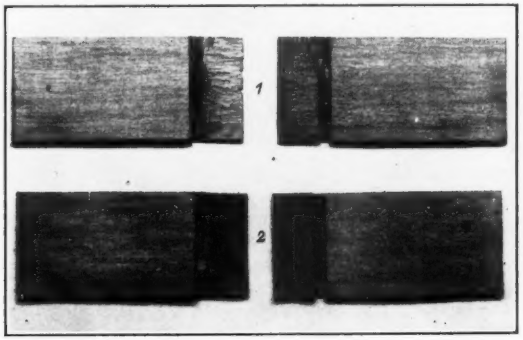

FIG. 38.

Aircraft Plywood (Blood Albumin Glue) after the Test.

Appearance of the test sticks after testing the glueing strength.
Glue test of birch plywood with blood albumin glue (usual plywood glueing).
1. Above.—Dry test; breaking in the wood; good glueing strength.
2. Below.—Wet test; shearing in the glue surface; bad glueing strength.

In the Material Department are carried out corrosion tests.

We have succeeded in protecting light metal alloys, used in our country, in a much better manner than previously. I may show that fact with simple examples (Figs. 40 and 41).

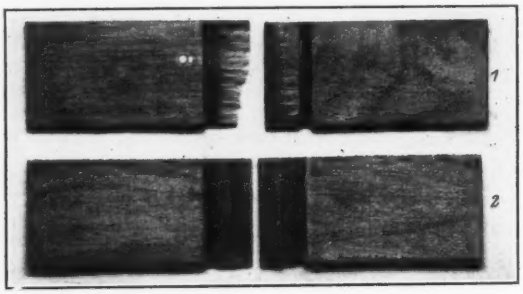

FIG. 39.

Aircraft Plywood (Artificial Resin Foils) after the Test.

Appearance of the test sticks after testing the glueing strength.

Glue test of birch plywood with double glueing by artificial resin foils (new plywood glueing).

1. Above.—Dry test; breaking in the wood; good glueing strength.
2. Below.—Wet test; breaking likewise in the wood; good glueing strength.

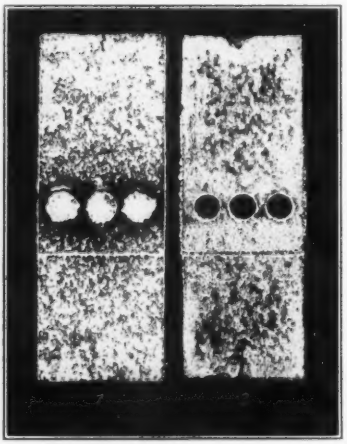

FIG. 40.

Protection of an Aluminium Alloy from Corrosion by a Covering Layer (Plating).

Duralumin with warm rolled-on covering layer (Duralplat). Electrolytic protection of the plating around the rivets.

On the left (1).
Sheet: Duralumin 681 b 1/3.
Rivets: Duralumin 681 a.
The rivet heads are strongly corroded.

On the right (2).
Sheet: Duralplat.
Rivets: Duralumin 681 a.
Same amount of corrosion as before.
The rivet heads are intact.

The DEPARTMENT FOR AERIAL PHOTOGRAPHY AND NAVIGATION, headed by Prof. Dr. Ing. O. Lacmann, carries out work which has important contacts between the branches already mentioned; the problems of navigation and the problems of photogrammetry are both of geodetic nature.

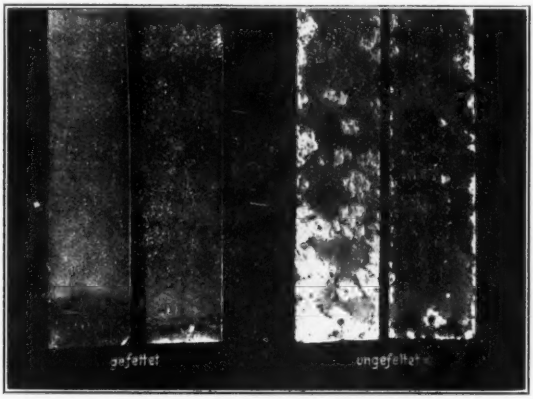

FIG. 41.

Protection of an Aluminium Alloy from Corrosion by Covering Layer (Plating), Oxidation and Greasing.

1 mm. Duralplat sheet anodic treated after the method of Bengough. Appearance after nine months in 3 per cent. salt water.

On the left: Greased.
Tensile strength: 38.3 kg./mm².
Elongation: 16 per cent.

On the right: Greased.
Tensile strength, 36.6 kg./mm².
Elongation: 12 per cent.

The greased sheets show no external variation and no diminution of tensile strength or of elongation.

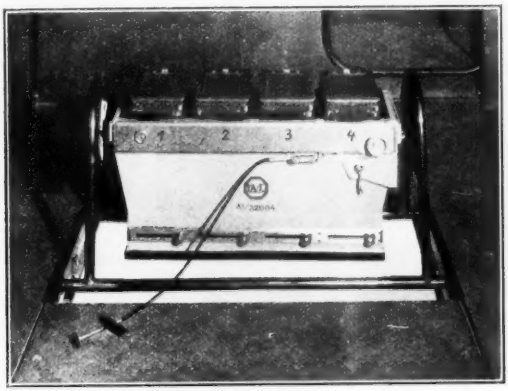

FIG. 42.

"DVL"—Manifold—Camera.

For the comparison of photographic emulsions and filters.

The camera allows four photographs of the same ground and at the same time with identical objectives and shutters.

In this department we test various photographic emulsions for their use in the aerial camera (Fig. 44). In that respect the increase of light sensitiveness, especially of the red sensitiveness, is very important. We have succeeded in bettering to a considerable degree the properties of photographic plates for aerial photographs over commercial plates.

In order to confirm our investigations in the laboratory by flight experiments, we constructed the Manifold Camera (Figs. 42 and 43).

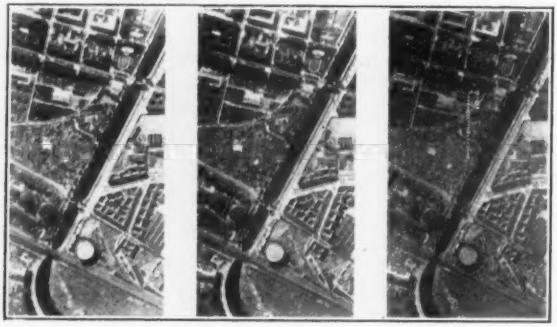

FIG. 43.

Comparing Photographs taken with the "DVL"—Manifold—Camera.

Time of exposure: 1/120 s.
All plates in the same manner normally developed.

On the Left.
Poorly sensitive, very fine granulated panchromatic plate, hypersensitised according to "DVL" method.

In the Centre.
Highly sensitive, panchromatic plate (very sensitive to red), steeply graduated.

On the Right.
Highly sensitive panchromatic plate, softly graduated.

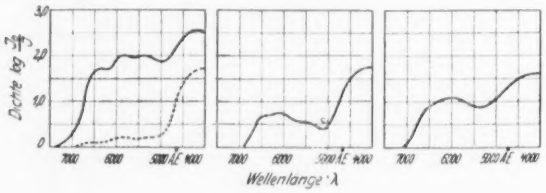

FIG. 44.

Curves of Blackening from Three Emulsions.

Abscissæ: Wavelength of light in R.u. Ordinate: Density log J_0/J.

Power of reaction:

..... before } Hypersensitive according to "DVL" method.
——— after }

On the Left.
Poorly sensitive, very fine granulated panchromatic plate, hypersensitised according to "DVL" method.

In the Centre.
Highly sensitive, panchromatic plate (very sensitive to red), steeply graduated.

On the Right.
Highly sensitive panchromatic plate, softly graduated.

For a photogrammetric ascertaining of the qualities of aeroplanes during getting-off and landing, Carl Zeiss, Jena, constructed the "DVL" getting-off measuring camera according to plans of the "DVL" (Figs. 45-47).

In the province of air navigation we investigated recently the relative altimeters with echo sounding according to Dr.med.h.c. Behm (Fig. 48).

For the photogrammetric and navigating research we use as a flying labora-

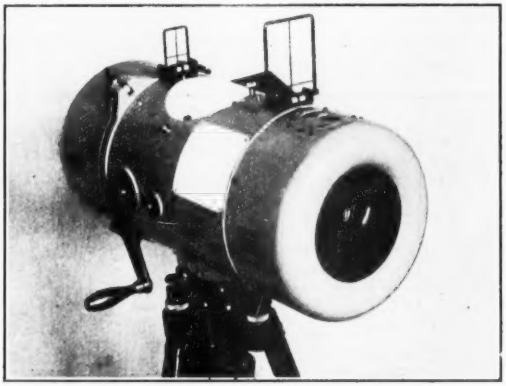

FIG. 45.

"DVL" Getting-Off Measuring Camera.

1. Constructor: Carl Zeiss, Jena.
2. Optical equipment: Teletessar 1:6.3, f=40 cm.
3. Film material: 16m. long film, 8 cm. broad, sufficient for about 100 pictures 7×12 cm.
4. Quick succession of pictures: About 1 picture per second.
5. Purpose of the camera: The camera serves to photograph during getting-off and landing the path of an aeroplane and to time it.

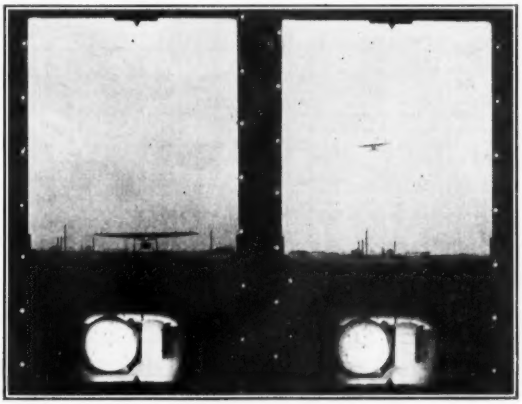

FIG. 46.

Getting-Off Measuring Pictures.

From the size of an image of a known dimension (for example, the span) of the aeroplane in the picture the distance of the aeroplane is determined. From the distance and the height of the figure of the aeroplane over the horizon the actual height of the starting aeroplane can be calculated. Together with the taking of the picture a stop-watch is photographed.

tory a " Möve " aeroplane of the Focke-Wulf A.G., Bremen (Fig. 49). Floor and sides of this aeroplane can be opened. The aeroplane possesses also a dark room.

The ELECTROTECHNICAL AND WIRELESS DEPARTMENT is headed by Prof. Dr. H. Fassbender. In the sphere of radio telegraphy we investigated the broadening between aircraft and the land station, theoretically and practically, both in the range of long waves, and in the range of short waves. The radio equipment is developed from the " DVL " in collaboration with the German industry. The long wave apparatus became so simple that a separate wireless operator was not needed on board. This apparatus is not provided for telephony as according to theoretical and practical researches of the " DVL " in agreement with service

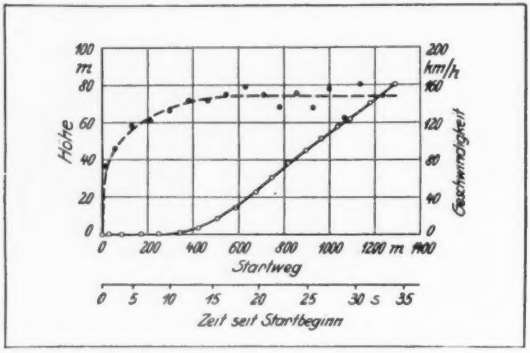

FIG. 47.

Results of Getting-Off Measurements.

Abscissæ { Upper scale: Length of getting-off path (*m*).
Lower scale: Time since beginning of get-off (*s*)
Ordinate { Left scale: Height *h* (*m*).
Right scale: Speed *v* (*km./h.*).

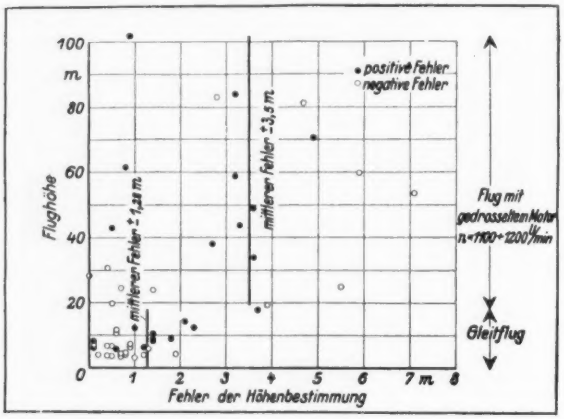

FIG. 48.

Accuracy of Acoustic Sounding in Aeroplane.

Abscissæ: Errors of height measurement in m.
Ordinate: Height of flight.
• Measurement too low.
○ Measurement too high.
Average error for heights 18-100 m.: ± 3.5 m.
Average error for heights 4-18 m.: ± 1.3 m.

experiences of the Deutsche Luft Hansa, telegraphy is, in commercial flying, superior to telephony. To these theoretical reasons there is added the poor understanding in telephony due to speaking in a foreign language.

As an example of the investigations of the broadening of long waves, I show you the result of a measurement in flight (Fig. 50). During the flight the receiving intensity of electric field as a measure of loud force according to distance from

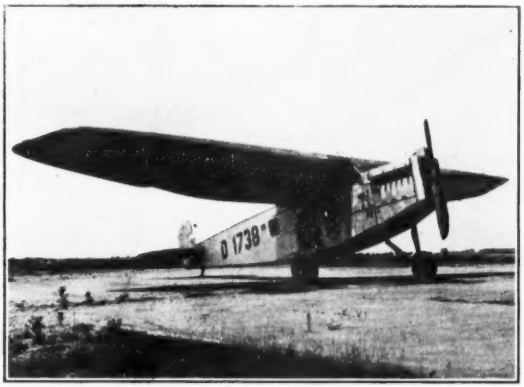

FIG. 49.

Flying Laboratory.

"Möve" ("Gull") special monoplane of the Focke-Wulf A.G.

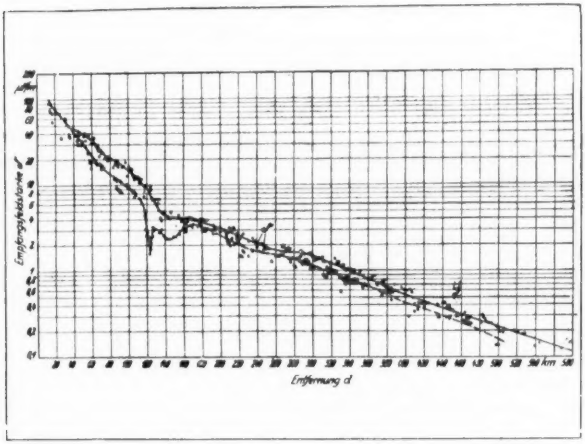

FIG. 50.

Results of Measuring the Intensity of Field during a Test Flight.

Ordinate: Intensity of field.
Abscissæ: Distance.
Lower line: Flying from Berlin to Amsterdam, 31/11/29.
Upper line: Flying from Amsterdam to Berlin, 1/11/29.
International aircraft wave-length: = 950 m.

The lower line shows disturbance in flying over the Elbe in consequence of peculiar nature of soil.

the transmitter, was determined. By means of such lines the " DVL " calculated an empirical spreading formula over land. This formula is accurate for the estimate of the distance of any station in advance (Fig. 51).

In further research we studied the problem of increasing the effective height of the aeroplane antenna by a suitable form of the trailing antenna. Theoretical

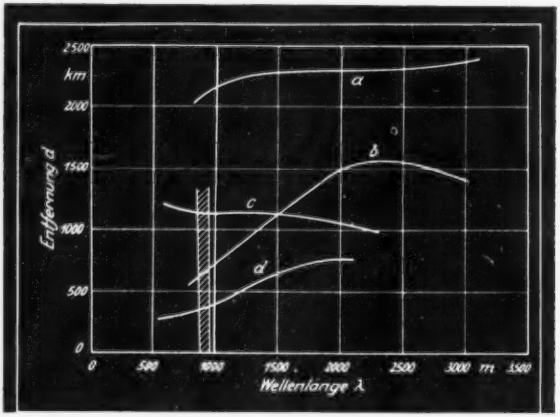

FIG. 51.

Extensions Computed by Empirical " DVL " Formula.

Abscissæ: Wave-length.
Ordinate: Extension of spreading.

(*a*) Over sea. } Airship apparatus.
(*b*) Over land. }
(*c*) Over sea. } Aeroplane Apparatus.
(*d*) Over land. }

Notice the great increase of range over land with increasing wave-length. Over land the international wave-length of nowadays is unfavourable for aircraft. The range of aircraft wireless is especially marked.

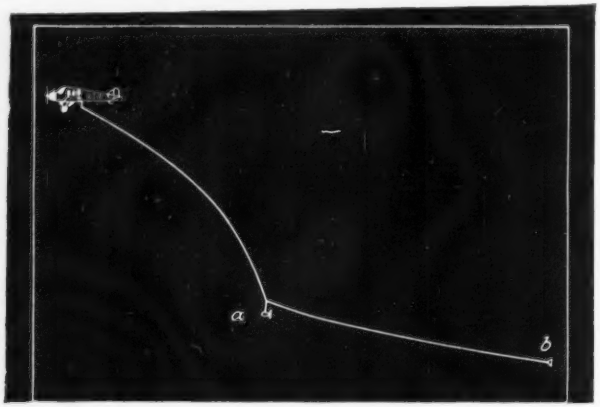

FIG. 52.

New Aeroplane Antenna of the " DVL."

(*a*) Streamlined weight with fins for the bettering of the radiating qualities of the antenna (" Lead Fish ").
(*b*) Extension for the increase of antenna capacity.

calculations and experimental investigations have shown that it will be practically possible to raise the effective height of the common trailing antenna by two to three times (Fig. 52).

Investigations with short waves, which in the beginning caused great difficulties in receiving, resulted in such progress that last summer a short-wave wireless trial service was in operation on the long commercial transport lines of the Deutsche Luft Hansa (Fig. 53).

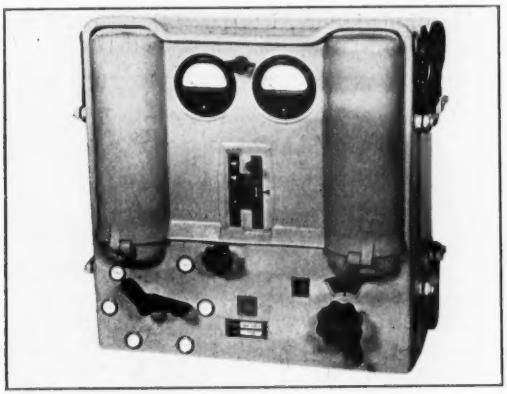

FIG. 53.

New Short Wave Transmitter Built by Telefunken.

Power, 30 W.
Wave-length, 26-27 m.
Transmitting: Soundless, sounding, and telephony range up to 2,000 km.
Weight of receiving and transmitting apparatus complete, 40 kg.

The FLIGHT DEPARTMENT of the "DVL," headed by Mr. Joachim von Köppen, has the important task of testing the flying qualities of new aeroplane types during trial flights and to suggest alterations if necessary. Safety in flight requires certain minimum demands in the flying qualities, *e.g.*, stability, controllability and manœuvrability. Particular importance is attached to great stability with free controls. Our experience has shown that great stability, even with aeroplanes of large size, does not exclude good controllability and manœuvrability. Our last observations on trial flights proved that we have succeeded in getting the newer types of German transport aeroplanes so stable that these aeroplanes can be flown hands off even in very bumpy air. These qualities are of great importance for blind flying (*e.g.*, flying in fog).

An important research of the Flight Department is that dealing with stalled flight. Spinning is unnecessary. In close collaboration with the industry and research laboratories we are trying to eliminate the causes of accidents due to spinning or incipient spins. This can be made possible by:—

1. Either by preventing the reaching of large angles of attack by suitable construction (for example, the Focke-Wulfe-"Ente," ("Duck"); Fig. 54).
2. Or by suppression of the autorotation of the stalled wing by suitable design of wing.
3. Or by getting sufficient controllability in stalled flight.

The results of flight tests with the "Ente" are very encouraging. I believe that Mr. Focke will report upon these tests at the coming meeting of the Wissenschaftliche Gesellschaft für Luftfahrt (Scientific Society for Aeronautics).

In order to get sound analytical foundations for the development of flying qualities we must have flight tests. The measurement of static stability is, in principle, made by adding additional moments of known size about the axis concerned (Figs. 55-57). The resulting steady condition is recorded by marking the dynamic pressure, the control force and the inclination of the axis concerned to the horizon. The additional moments are suddenly removed and the dynamic behaviour of the aeroplane observed by recording the angular motion following this disturbance.

At the beginning of my lecture, I told you that I could not give you a very comprehensive report. That is not possible because the " DVL " carries out much

FIG. 54.

Focke-Wulf-" Ente."

The front wing of the " Ente " is higher loaded than the main wing. Thus the front wing reaches its maximum lift at lower angles of attack than the main wing. Stalling of the main wing is so made impossible.

FIG. 55.

Testing Arrangement for Measuring the Static Aileron Action and the Damping about the Longitudinal Axis.

On the wing tip is fixed a ballast bag. The moment of its weight is in flight balanced by aileron angle. The latter is measured for the static aileron moment.

After throwing off the ballast bag, the aeroplane makes an angular displacement around the longitudinal axis. By measuring the angular motion due to time we find the damping about the longitudinal axis.

research of a confidential character. Many important problems are only treated between the "DVL" and its employer. It is always a great satisfaction for us to be able to help the aircraft industry or the aircraft users.

The original announcements of my lecture before your Society mention the researches at the Technical University of Berlin. I have spoken chiefly about the work of the Deutsche Versuchsanstalt für Luftfahrt, and I must now tell you something about the collaboration between the Deutsche Versuchsanstalt für Luftfahrt and the Technical University of Berlin.

At the Technical University of Berlin the students attend lectures and carry out work necessary for the courses. The different laboratories of the Deutsche

FIG. 56.

Testing Arrangement for Measuring the Stability about the Lateral Axis.

Sand bags on the fuselage stern produce weight moments about the lateral axis. After throwing off the sand bags a disturbance about the lateral axis arises, the course and time of which are recorded. The pitching motion is recorded by photographing the horizon with a film camera fixed at the aeroplane.

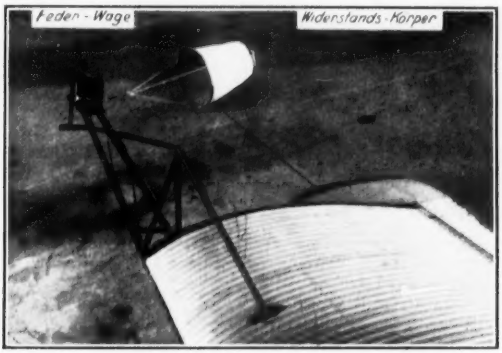

FIG. 57.

Testing Arrangement for Measuring the Stability about the Normal Axis.

At the wing tip, resistance bodies are mounted, which produce moments about the normal axis. The resistance of each body is measured by a recording spring balance. For the determination of the dynamic behaviour about the normal axis, the resistance body is thrown off suddenly by burning away the fastening cord.

Versuchsanstalt für Luftfahrt, at Adlershof, also serve for students' instruction. A number of collaborators of the " DVL " act as teachers of the Technical University. This combination has proved satisfactory. In this way we are able to let the students benefit directly by the experience of our research.

The aeronautical instruction of the Technical University of Berlin is in close collaboration with the instruction in mechanical engineering, in preference to that in naval architecture and marine engineering. The students can pass their final examination in aircraft engineering. For this examination the students must have a thorough knowledge and training in all branches important for aircraft engineering.

The students interested in flying have a students' flying club in Berlin. Such flying clubs exist at nearly every German Technical University. Our successes in soaring flight at the Rhön and the many excellent flying performances with low-powered aeroplanes are due to these flying clubs. I am very glad to work as a professor in close touch with the students' flying clubs.

Aircraft engineering progresses in many directions. It will therefore not have astonished you to note the wide range covered in the lecture.

A joint meeting will be held this summer by the North-East Coast Institute of Marine Engineers and Shipbuilders, at Newcastle-upon-Tyne, perhaps also by the Institute of Naval Architects, together with the Deutsche Schiffbautechnische Gesellschaft in Germany.

In conclusion, I hope I have succeeded in giving you a review, though somewhat restricted, of work of the " DVL."

Discussion

The President: He expressed the sincere gratitude of the Society to Dr. Hoff for the extremely interesting and comprehensive paper which he had given, and at the same time, remarked that whilst the paper had been greatly appreciated by the audience at the meeting it would also be equally appreciated by the much greater audience which read the Journal. Dr. Hoff had even taken the trouble to prepare special slides with captions in English in large numbers for the purpose of illustrating his paper. The President also expressed the thanks of the meeting to Mr. Glauert for having come forward at a moment's notice and helped Dr. Hoff in reading the paper, in view of the fact that Dr. Hoff had not been very confident as to his command of the English language. They were honoured that evening by the presence of some of the greatest scientists in the country connected with the subject of aeronautics. The paper was perhaps not a controversial one, but there were many points which were of interest to them and they would all be greatly interested in any observations which the scientists present might be willing to make. He asked Sir Richard Glazebrook to open the discussion.

Sir Richard Glazebrook, F.R.S.: He felt in considerable difficulty in speaking in a discussion of the paper, because of the amount of material contained and the wide range of the subjects dealt with. Thus it was almost impossible to discuss in detail anything more than a very small part of the material. Dr. Hoff had explained how in Germany they were meeting problems which we also had to face in England, and those who had done work in this country towards the solution of those problems would agree that, in the methods Dr. Hoff had explained and the descriptions of the apparatus he had given, great progress has been made in Germany towards solving many difficult questions. At the same time, the paper helped them in England to realise how solutions might best be obtained and how the problems might best be attacked. He did not propose, however, to discuss matters of that kind, because he was not really competent to speak on the actual details of the measurements Dr. Hoff had made, and the instruments that had been described. There were others present who could do that with very much more advantage, but there were a number of points in the

paper of general interest upon which he would like to say a few words. In the first place, he wished to call attention to the importance which Dr. Hoff had given to international co-operation in all these questions. That was realised very fully in this country where it was a matter of great gratification that there should be close co-operation between their own Inspection Department and the German Department which Dr. Hoff so admirably and so excellently directed. It was of great interest to them that there should be international agreement on the question of airworthiness and matters of that kind. In this country they were most anxious that that policy should be continued and strengthened in any way possible, and those who were working on the scientific side of these questions in this country welcomed very thoroughly and fully all that Dr. Hoff had said, and hoped that in the future they would continue to have as much co-operation as possible. With regard to that side also, he could assure Dr. Hoff that they appreciated very fully indeed the work that had been done in Germany by Prandtl and his school at Gottingen, and by Von Karman at Aachen. The papers of those two distinguished writers and their pupils were read with the greatest interest in this country because the information and knowledge which they gave was of the very highest value.

In the earlier part of the paper Dr. Hoff had referred to a problem which had recently given some of them in this country a very considerable amount of thought and care, namely, the cause of what was known as the Meopham accident; those concerned with that enquiry wished to thank Dr. Hoff for the assistance which his organisation had given to the Accidents Committee and others investigating that accident. They looked forward with very great interest indeed to what the D.V.L. had to say on that matter, and wished to thank them for the promise to communicate to the Aeronautical Research Committee their Report on the accident. He was convinced that only in this way could technical development in both countries be advanced; such co-operation was of the greatest importance and of very great value.

In looking through the paper one or two of the instruments described had appealed to him as being particularly beautiful and valuable. For instance, there was the strain recorder for measuring the elongation of parts of aircraft. There was also the work done on the measurement of airscrews, and the camera that was used for measuring vibrations of parts of airscrews. There was a reference in the paper somewhere to the results obtained with model airscrews, and it would be interesting to know whether these model experiments were borne out on the full-scale aircraft. He had not been quite certain in looking at the description of that apparatus whether it was to be used in the laboratory mainly, or only, whether it was capable of being employed actually on an airscrew on an aeroplane in flight. Another piece of apparatus which appealed to him as being of very great interest was one in which there was shown a means of measuring the vibrations due to the alternating stresses of various kinds superposed on the steady load on the spar of an aeroplane wing. Another piece of apparatus of outstanding interest was the Optograph, which enabled the measurement in the air of the oscillations of various parts of the machine when actually in flight. Again, he could not help commenting on the method described by Dr. Hoff for measuring the pressure changes that take place in the cylinder of an engine. That employed a method which they had used in England in various other ways for measuring small changes—the method of variation of the capacity of a small condenser—which was developed a little time ago very fully and very elaborately by Professor Whiddington of Leeds for other purposes.

These were only a few of the points that had occurred to him in glancing through the paper, with perhaps the exception of one sentence at the end where Dr. Hoff said that he had only been able to give a restricted view of the work that was being done at the D.V.L. If the paper represented a restricted view of the work undertaken by the D.V.L., what must the total of that work be?

In conclusion, Sir Richard Glazebrook again assured Dr. Hoff that everybody appreciated very thoroughly indeed his great kindness in coming to England and giving them all this information. It must have involved himself and his staff in a tremendous amount of labour and trouble to prepare the paper and the slides.

Mr. H. E. Wimperis (Director of Scientific Research): Dr. Hoff's own organisation at Adlershof was in many ways similar to the Farnborough organisation. At any rate, there seemed to be a nearer parallel with that than with any other organisation in this country and he hoped Dr. Hoff was interested in what he had seen at Farnborough. It would be interesting if Dr. Hoff would say whether his experiences at Adlershof had shown there was any particular piece of work or piece of apparatus which he felt Farnborough lacked. There could be no objection to stating that publicly because it was a Government organisation and therefore everybody present really constituted a shareholders' meeting! He also congratulated Dr. Hoff on the excellence of his English, and said it was really quite unnecessary to have Mr. Glauert read the paper, except that of course it was a great assistance in that it enabled Dr. Hoff to deal separately with the diagrams. It was impossible to refer to Mr. Glauert's name without parenthetically remarking how glad everybody was to see the very high honour done to him a few days ago in his election as a Fellow of the Royal Society.

Last autumn Mr. Wimperis had had the advantage of visiting Berlin and going to Adlershof where he was cordially and charmingly received by Dr. Hoff and his staff of assistants. Every possible facility was placed at the disposal of Mr. Garner and himself and they saw a great deal of immense interest and spent a very busy time. On that occasion they had seen, so to speak, in the flesh, most of the apparatus which Dr. Hoff had shown on the slides that evening. The instrument which interested him most of all, perhaps, was the diamond scratching device for recording pressures on the hulls of flying boats and the floats of seaplanes, and by the great courtesy of the D.V.L. he had been able to obtain, with the assistance of the Air Attaché at Berlin, several sets of this recording apparatus, and he understood from Dr. Hoff that these were now on their way to this country where they would be put to immediate use at Felixstowe. That was one instance of co-operation and another one was the method of measuring the drag on hulls of flying boats and floats of seaplanes. That was already being followed in this country and the information which he obtained when he was at Adlershof had really been of fundamental value in guiding the work they were doing in this country in building a similar apparatus for a similar purpose.

Professor Bairstow (Zarahoff Professor of Aeronautics, Imperial College): He associated himself with what had been said by Sir Richard Glazebrook and Mr. Wimperis upon the international aspect of Dr. Hoff's visit to this country. Professor Prandtl had previously lectured to the Society and he hoped as time went on that they would welcome other people from Germany and other parts of Europe. It was fair to say that international co-operation on the scientific side was quite good and he wished to support Sir Richard Glazebrook's suggestion that countries should agree to a common basis so that they could accept each other's certificates of air worthiness. That would facilitate the development of flying through Europe and through the world generally and, of course, be of the greatest possible good for aviation in general.

Speaking with regard to the instruments described in the paper, he had been specially interested in the scratch recorder for stresses in aircraft and the use which could be made of that instrument. He gathered that measurements of the loads in aircraft in bad weather had been made. It was one of the most important matters in designing aircraft to know what loads would be met with, first of all in normal transport and secondly in bad weather, and he

would be very much interested if Dr. Hoff could say whether as the results of his experiments, information had been obtained as to whether the loads due to gusts were greater as compared with those due to flattening out, and if so whether these observations had been taken in bad weather of the thunder type or whether they had been taken in what might be called normally bad weather.

In describing the apparatus for measuring the oscillations of airscrews, Dr. Hoff had shown an optical device which was well known in this country and at the same time he had made the remark that for the purpose of producing the slide in question, a screw had been designed with known frequencies of oscillation. If Dr. Hoff was in the fortunate position of knowing how to calculate the frequencies of airscrews, then they in this country were in the position of wishing to go to him for assistance. It was quite true that they had designed a special screw for very much the same kind of experiment, and many of those present had seen on the screen of a camera the torsional and bending oscillations of the screw. At the same time, they felt they had a long way to go before reaching the position of a complete understanding of torsional and bending oscillations of airscrew blades.

Another experiment which interested him in the paper related to spinning. There would be general agreement with Dr. Hoff in his suggestion that spinning is not necessary, but beyond that there was room for many different points of view. The first method of avoiding spinning referred to by Dr. Hoff was that of preventing the stall. There was one ingenious machine shown which had a front wing which stalled before the main wing, and it was clearly possible to retain control by keeping the angle of incidence below a particular value. Such an effect could be produced by reducing the amount of elevator control, but although it was known and agreed that the effect could be produced by that means, was the effect so produced a desirable one and was the aeroplane so limited a good machine for ordinary purposes? The next method of avoiding spinning which Dr. Hoff had spoken of was the prevention of auto-rotation of the wing. It was known that that could be done to a considerable extent by twisting the wings, but again the effect had to be paid for by a loss of aerodynamic efficiency. Was it possible to get the very efficient aeroplane which was necessary for commercial success and at the same time so construct the wings that auto-rotation was not possible? The evidence was rather against the possibility of such a combination. In this country they had gone rather more in the direction of trying to get all the advantages out of high efficiency wings whilst providing adequate control, and that was the third of the methods which Dr. Hoff described as being under consideration in Germany. He would be very much interested to know if Dr. Hoff could give an idea as to which of these methods was the more generally favoured.

Professor SOUTHWELL: He asked whether facilities were available at the D.V.L. for the construction of the instruments which the author had illustrated. He had been very much impressed with the ingenuity of the instruments, and was wondering where they were made. In this country, if such instruments were ordered in quantity from the workshops of the research establishments congestion of work and hence delay resulted; if, on the other hand, an endeavour was made to get the instruments constructed by outside firms, troubles with contracts and tenders usually arose, which sometimes had the effect of making deliveries later still. He wondered whether this problem had been encountered by the D.V.L., whether they had extensive workshops in which the instruments could be made quickly, or whether the instruments were made by outside firms, and if so, whether prompt delivery was given.

The only other question he would put now was in regard to the measurement of torsional vibration in a crankshaft but he was not quite clear what mechanism was provided for producing an oscillatory torque, and he would be interested to know what method was adopted.

Mr. HANDLEY PAGE: He expressed his great interest in the instruments that had been described and expressed the hope that some of the results that had been obtained with them would be made available. He was not aware whether any of the tests had been published. The results obtained on spars had specially interested him. He would like to know whether any of the results obtained by the use of the extensometer had been published. Another matter upon which information would be valuable was the actual braking effects recorded with the apparatus illustrated in Fig. 22, by means of which measurements had been made on different landings. Had any such results been published, because if so, he would like to have a reference to where they could be consulted. Another matter which interested him was the research work on three-ply wood. Ply-wood was often looked upon with great disfavour in this country as being a material liable to undergo severe changes with different atmospheric conditions. For example, in a very wet climate there might be an entirely different effect to that obtained in a dry climate, and he would like to know whether the material prepared according to the new process described in the paper had shown an increase in the lasting strength. It rather seemed that by covering the wings with a good three-ply material it should be possible to reduce somewhat the frictional drag on the wings, at least in comparison with a corrugated structure. Were any results with this new type of material available? The photograph of the Focke-Wulfe machine interested him and it would be useful to have some results of the flying qualities of it. It would appear that the rudder control must be somewhat small, the rudder being so near to the centre of pressure and gravity of the machine. Again, he would like to be able to consult some results with that machine.

Major A. R. LOW: He was glad that the international aspect of aerodynamical research was brought into prominence. The healthy reaction of German research on work in this country was known to and acknowledged by everyone present. It was a considerable part of his own duties to read, as widely as he could, German technical work and bring selected papers to the attention of their own technical staffs. Twenty years ago aeronautical engineers were hungry for information and snapped up eagerly every bit of published information. Now they were positively liable to indigestion from the glut of published work. He therefore suggested that an effort should be made to keep down the quality of published work and to maintain a very high standard. Even first-class papers could often be cut down to half the number of words without losing anything of value.

With regard to the paper they had heard that evening, it was a condensed summary of a wide range of first-class work, and every word was of value. He thanked the author for giving, in English, so admirable a survey of the great activity in German aeronautical research.

Major CARTER: He had been specially interested in the work done at the D.V.L. on torsional vibration and the development of the instrument described by the author. They had a somewhat similar instrument which gave good results, although the recording arrangement was cruder. Most of the experiments they had carried out with vibration, however, had been made with an instrument fitted in the airscrew driving shaft. Although this instrument had some advantages, it did not always give a very accurate measurement of the amplitude of the vibrations in the shaft. Had the author, from the measurements he had made with his instrument, been able to determine sufficient about damping factors in aircraft engines to make it possible to predict from the calculations how serious the torsional vibrations would be under flying conditions?

Mr. LYNAM (R.A.E., Farnborough): He welcomed the opportunity of joining Mr. Wimperis in acknowledging the great courtesy and kindness Dr. Hoff and the members of his staff at D.V.L. extended to both himself and Mr. H. B. Howard when they visited Germany last September. As the result he also had enjoyed the privilege and advantage of seeing most of the instruments that

had been described, and also of conversing with the designers and users of the apparatus.

The main question he had intended to put to the author had already been mentioned by a previous speaker, viz., whether at D.V.L. they were able to calculate the flexural and torsional periods of the blades of airscrews in rotation, as was suggested in the lecture. If, therefore, it was possible to estimate the flutter speeds of airscrew blades, he would be very interested to know the methods used and to have an indication of the accuracy with which the estimates can be made. He would also like to know whether the methods are such as can be used in designing airscrews to avoid flutter, and whether such calculations are normally made by airscrew designers in Germany.

Whilst blade flutter had long been a source of serious uncertainty in airscrew design in this country, up to the present time no method of ensuring avoidance of flutter was known. This was largely due to the exceedingly complex nature of the problem.

Like many other parts of the aircraft structure, it was becoming increasingly important to design to stiffness rather than strength standards. These standards were, however, very difficult to define and estimate and to the speaker this appeared likely to prove the most difficult problem confronting aircraft designers in the future.

Another point of outstanding interest in the paper was the work in progress at the D.V.L. aiming at the determination of the effects of bad weather—gusts and bumps—on the strength of the wing structure, and more particularly the spars. The speaker presumed the problem was to determine the magnitude of the dynamic loads arising from gusts, etc., to be imposed on the static load in design. It appeared to the speaker that this was a difficult matter, if only because it involved flying over very long periods of time, with different types of aircraft and in different parts of the world. Only in that way would it be possible to determine the dynamic loads likely to occur due to atmospheric disturbances for which provision must be made in the design of commercial aircraft which can otherwise have low factors. For this reason the speaker thought that the accelerometer, although not giving so directly the information required, was the more practicable type of instrument to employ as extensively as is necessary to give the data required.

It is believed that the method is to determine the frequency with which wing movements of different amplitudes occur, and from this data to decide the amplitude of movement which is likely to occur sufficiently often in the use of the aircraft to necessitate the corresponding dynamic load being taken into account in the determination of strength based on the fatigue limit of the material involved.

This assumes that the effects of such movements occurring at irregular intervals and possibly with relatively long rest periods interposed, have the same effect on the material as when maintained in vibration with the same amplitude until failure occurs. There is little doubt that the assumption involved is on the conservative side, but it may be that the effect on the weight of the spars will be considerable.

Dr. LACHMANN (Messrs. Handley Page): For a German who had enjoyed extended hospitality in this country it was very pleasing to notice the appreciation of German aeronautical research work by the Royal Aeronautical Society, and to hear the views that had been expressed with regard to future co-operation.

Up to the present the exchange of views had been perhaps a bit too one-sided in so far as only German research workers had come over to this country and had reported on their field of work. He hoped that a return visit of British research workers to Germany would take place some time in the future, so that German aeronautical circles might benefit from their knowledge and experience, especially on subjects which were less cultivated in Germany.

With regard to the lecture itself, he wholeheartedly agreed with Dr. Hoff that spinning was unnecessary and should, therefore, be abolished. He believed that this could be done without spoiling the efficiency of an aeroplane, although it might rob the scientist of a problem which had been dear to his heart on account of its complexity.

Another important point was the research work which had been done in regard to deflections in flight. He was convinced that an intense study of this problem would lead to a revision of load factors now in use for large aeroplanes. They were inclined to imagine that loads on large aeroplanes were less than on smaller aircraft owing to the slower movement of the bigger machine. In regard to atmospheric influences, however, *e.g.*, wind gusts, he believed that large aeroplanes might be subject to loads of the same magnitude, as compared with smaller aircraft, although those loads might be more localised.

Dr. Hoff had described the vast amount of problems with which the D.V.L. was dealing, but he very modestly left out one very serious problem, viz., the problem of making both ends meet. This was a specially difficult one owing to the financial position in Germany at the present time.

Mr. D. R. Pye (Assistant Director of Scientific Research): He referred to the very beautiful time pressure records taken from an engine cylinder which had been shown on the screen, and said he would like to have from Dr. Hoff, in the form of a written reply, some indication of the method by which the pressure scale was obtained on an instrument of that kind could be relied upon to maintain constancy of the pressure scale from day to day. There need be no difficulty in getting a sufficiently accurate time scale, and if one could also get the pressure scale accurate and reliable it would provide an instrument of extreme flexibility and importance. He had been asked to say something in the way of rounding off the discussion, but the general aspects of the paper had been so adequately dealt with by the distinguished leading lights who had spoken earlier in the discussion that there was really very little more for what he might call the tail light to do. The paper had not only been fascinating to listen to, but would also be of lasting value to people in this country, because when it was printed in the Journal it would constitute a yard stick by which they would be able to measure their own ignorance and see what were the loopholes in our information which they must try to fill in by following the example of the D.V.L. He would conclude by adding one word more of thanks to Dr. Hoff on behalf of the audience.

Mr. C. C. Walker (Director, De Haviland Aircraft Co., Ltd.) (*Communicated*): The extensive development of full-scale measurement and research at the D.V.L. is particularly interesting. It suggests to one's mind that possibly the absence of a wind tunnel at the D.V.L. is a disguised blessing in that it has enabled Dr. Hoff to concentrate more on the work which is illustrated in his paper. He had always thought that the wind tunnel was more suited to systematic research for checking and developing aerodynamic theory than for "ad hoc" experiments on complete machines, and perhaps this view is rather borne out by Dr. Hoff's lecture.

There are many questions one would like to ask. Presumably the record of the extensometer Fig. 1 is made on smoked glass. What time range can be obtained in this way and how is the necessarily very slow traverse of the glass arranged? The instrument is particularly neat. Although the main differences in the kind of information obtained by means of the extensometer and that obtained by accelerometer records are obvious, it would nevertheless be interesting to have Dr. Hoff's comments on these two ways of determining the loads transmitted from wings to fuselage.

Dr. Hoff refers to the fatigue failure of wooden spars under vibration. This must be an entirely different phenomenon to fatigue in metals, and if he

has any quantitative information as to the effect of reversal of load on the maximum permissible stress, this would be extremely interesting.

On the question of spinning he could not help thinking that the endeavour to prevent the aeroplane from reaching a stalling attitude is the least satisfactory method since it involves limiting the fore and aft control, and further if it is desired to so limit the control, it is surely just as easy to do this on an orthodox aeroplane by putting stops on the elevators. It would then be very difficult to see any difference between such an aeroplane and the "Ente" so far as the ability to stall is concerned.

Speaking as one who is very much concerned with civil aviation, it would be hard to exaggerate the pleasure one feels at establishing personal contact with the D.V.L. through Dr. Hoff. This kind of event, altogether apart from of great interest of his lecture, seems to bring nearer the frontier-abolishing effect which must inevitably follow the proper development of aircraft. The existence of international restrictions and a full development of air travel at the same time seems hardly possible, and one feels that the free interchange of information is one of the avenues leading to understanding and the abolition of restrictions.

Air-Commodore WARRINGTON-MORRIS (*Communicated*): There are one or two wireless matters which he would like to raise.

Fig. 49.—The lecturer states that long-wave apparatus has been so simplified that a separate operator was not needed on board.

This might be taken to mean that anyone can operate the wireless telegraphic set, but in reality a mechanic well trained in the Morse Code must be employed on operation. If the aircraft is signalling frequently during a flight, the mechanic keeps a continuous wireless watch, adjusts his apparatus and becomes, in effect, a wireless operator. Provided that he is well trained in Morse and procedure, no harm is likely to result, but a semi-skilled air operator is liable to interfere with signals between other aircraft and aerodrome stations with results that might be disastrous.

Fig. 51.—The curves given indicate that the International aircraft wave-length (which is 900 metres and not 950 metres as stated in Fig. 50) is too short.

The wave-length of 900 metres is a good one for the normal length of trailing aerial, viz., 250ft., and to re-design the W/T apparatus to give a longer wave-length and to use an aerial of about 500ft. is, he considered, a very retrograde step. In the first place, one does not require long ranges from aircraft on long waves. The mutual interference would disorganise communications. Secondly, the pilot already objects to a trailing aerial and the extension necessary, as indicated in Fig. 52, would be strenuously resisted by the pilot and the operator who had to reel it in by hand.

Thirdly, experience shows that a streamlined weight with fins is not of great value in bettering the radiating qualities of the antenna in high-speed aircraft.

Fourthly, curve C in Fig. 51 gives no indication of an increase in range with an increase of wave-length. The major use of wireless in aircraft is over land. Any increase of the International wave-length is, therefore, to be deprecated.

Captain D. SINCLAIR (*Communicated*): In the small space which Dr. Hoff has been kind enough to allocate to wireless in his excellent paper on the work of the D.V.L., it is of great interest to observe that so many interesting points have been raised on wireless.

He draws attention to the effect of the soil over which the machine was flying, upon the signals. This is the first time he had seen any real data on this matter and, in consequence, further details of these experiments would prove of considerable interest. As regards the diagram Fig. 51, it would be interesting to know if any effect has been noticed when the waves have been polarised vertically or horizontally?

It would seem that the use of long wave-lengths involves carrying trailing aerials—fixed aerials seem essentially necessary in all future aviation radio work, especially as radio is most useful in fog and other adverse weather conditions; at which time most pilots prefer to fly low and a trailing aerial cannot be let out. Short wave-lengths, possibly of the order of 70 to 100 metres, seem to give great promise for aviation services and these also can be utilised by means of fixed aerials. In this connection, further information on the Deutsche Luft Hansa short-wave investigations would be very welcome.

In conclusion, he would like to congratulate the D.V.L. on their most scientific and businesslike equipment shown in Fig. 53. This appears to be a real advance in the construction of aviation wireless equipment as distinct from a wireless equipment adapted to aviation requirements.

Reply to Discussion

In the discussion following my paper, several members expressed interesting opinions in regard to the different matters treated with and asked me certain questions. My reply to the discussion follows the order of the paper. This seems to be more suitable than strictly adhering to the questions of the speakers, which often cover the same field.

Several members asked more general questions. I may answer to these questions at first:—

(1) In reply to Mr. Southwell, the majority of the instruments shown were produced in workshops belonging to the D.V.L. For some years this method has proved best. In the Service Department of the D.V.L. we employ skilled workmen capable of co-operating with the research departments. Incidentally, instruments developed by the D.V.L. are also sold, but only if it does no economical harm to the instrument industry concerned.

(2) I agree with Major Low that one should try to limit the quantity of publications in aircraft science. But this is only possible if at the same time the research reports remain accessible in their original shape. For the practical engineer, however, reports are of special interest, which review the results of the research institutes of the whole world.

To Mr. Handley Page I may say that the research reports of the D.V.L. are currently published in the "*ZFM*" ("*Zeitschrift für Flugtechnik und Motorluftschiffahrt*") and in the "*LUFO*" ("*Luftfahrt-Forschung*"), both edited by R. O. Oldenbourg, München und Berlin. All reports are published yearly collected in the yearbook of the D.V.L.

Department of Airworthiness.

(3) With great interest I heard from Sir Richard Glazebrook and Mr. Bairstow that they are in agreement with me regarding an international recognition of airworthiness certificates. It is important that experts of the different countries should become acquainted with each other's examination methods and the technical reasons for them. Such acquaintance allows international recognition, not only from political considerations, but because of an honest mutual recognition of the technical performance of both countries concerned. Exchanging ideas that result from inquiries of flying accidents will contribute to a strengthening of international relations in aeronautics.

Aeronautical Department.

(4) In regard to the question asked by Mr. Walker, I wish to say something more about the scratching instrument.

The record of the elongation recorder is made by scratching a line into the glass surface with the pencil having a diamond tip. There is no prepared surface on the small glass plate. The lines scratched into the surface of this glass plate are very fine. With the best scratching pressure and with suitable angle

of nibbing of the diamond tip cones the width of a line is about 0.002 to 0.003mm. Such fine marking lines make it possible to use the instrument for the measurement of very small elongations, without becoming too broad with regard to the ordinates.

Under the microscope, these scratched lines are sharp and clearly visible in translucent as in direct light. Under good condition of the glass surface one can get enlargements up to 1,000 times and more, without the enlarged record becoming indistinct. An enlargement of about 200 times has generally proved suitable for practical use. With that enlargement the length of the records amounts to 5m. for all instruments having plain glass plates of 25mm. length.

The translational velocity of the small glass plate is chosen according to the task in question, in such a way that the details of phenomena to be recorded are sufficiently separated. During tests at fast oscillations the translational velocity has been so great that the glass plate passed during one second. With the usual enlargement of 200 times, a length of 5mm., when enlarged, corresponds to 0.001 second. Nothing prevents us from further increasing the translational velocity. But this has not been necessary till now. The instruments can also run very slowly. They are also used with thermographs, barographs, etc., with running times of about two hours.

The small glass plates are mounted on a sledge. They are pushed on by a screw spindle which engages with a nut fixed to the sledge and by which the latter slides along. The spindle is usually turned by an electromotor at variable speeds. These speeds are usually too high, and the electromotor is geared. A small change speed gear with two gearing ratios is directly mounted to the instruments. With respect to special problems, the speeds of the driving motor are suitably chosen, or one has to insert another gear or to replace the already mounted gear.

(5) In answer to Mr. Bairstow, the strain recorder is working on the same principle as the elongation recorder, except that this instrument uses a glass cylinder instead of a plain glass plate. The glass cylinder is mounted on a screw spindle and rotated around its axis by the electromotor. In consequence of this installation each point of the surface moves on a helical line. The base line of the record is consequently a helical line with a pitch of generally 1mm. The diameter of the glass cylinder is about 30mm. and so is its length. The recording length available is about 3m. With a running time of about 30 hours a time of 0.001 second corresponds to a recording length of about 0.002mm., and, when enlarged 200 times, to about 4mm. Very short timed phenomena may thus be observed.

Only a few examples of such strain recorders at present exist. They are installed in aeroplanes for measuring the elongations in suitable chosen structural parts during flight. I am not able to give you definitive results because of the small number of tests and flights yet carried out.

The results of flights under not especially unfavourable weather conditions proved that strains corresponding to 1.2 to 1.3 times gross weight are generally occurring, both in turning and in weather of light gustiness. The highest strain hitherto measured occurred in weather of average gustiness (no thunderstorm) and corresponded to 2.2 times the gross weight of the aeroplane.

(6) With regard to a question put up by Sir Richard Glazebrook, the optical installation for the observation of rotating airscrew blades used by the D.V.L. is only suitable for laboratory work. The same method has earlier been used in Germany for similar purposes. For example, Mr. Thoma, in München, explored turbine blades with a rotating prism.[1]

[1] In a description by Pritschow, "Zeitschrift des Vereines Deutscher Ingenieure," Bd. 69, S. 700, "Ein optisches Gerät zur Beobachtung umlaufender Teile in scheinbarer Ruhe (Rotoskop)," a reference is to be found, that this method is described in 1891 in the French paper "La Nature," S. 241, under the title "Le Cyclostat."

(7) Replying to the questions of Mr. Bairstow and Mr. Lynam, it is really possible to compute the self frequencies of airscrews with a certain approximation. The results of the method[2] are summarised as follows:—

The analytical estimate of the critical speed at which forced (unstable) oscillations occur, shows that this kind of oscillation is very improbable for airscrews of usual design, contrary to aeroplane wings. An airscrew blade possesses in proportion to the working aerodynamical forces a very high torsional stiffness. Moreover, only a slight coupling between torsional and bending vibrations of the propeller blades exists. Airscrew oscillations as a consequence of a periodical breaking away of eddies from the boundary layer are conceivable. But these oscillations are inferior to resonance vibrations due to irregular coming in touch with the air flow by the propeller blades.

The theoretical research is done by separate treating of the two degrees of freedom for torsion and bending. The very great difference between the two self frequencies of airscrew blades justifies this procedure.

The air forces are not important compared to the self frequencies of the propeller oscillations.

The torsional frequencies are so high that resonances between torsional oscillations and disturbances by an irregular stream field are almost totally excluded.

The bending oscillations are more thoroughly treated according to known methods found by Rayleigh. The results show that two airscrews which may differ from one another in all dimensions, material qualities, and—with broad limits—also in their form, but which have but the same proportion of hub length to blade length and the same self frequency in rest, also possess practically the same bending frequencies while rotating. Therefore it is possible to put forward a single formula as being approximately valid for airscrews of any dimensions:—where

$$\lambda/\lambda_0 = [\,1 + \eta(\omega/\lambda_0)^2/6 \pm \eta\omega/\lambda_0)\,]\;[\;\{\,1 + (1 + \epsilon S/\theta)(\omega/\lambda_0)^2\,\}\;/\;\{\,1 + (\omega/\lambda_0)^2\,\}\;]^{\frac{1}{2}}$$

ω = angular speed of airscrew
λ = bending frequency of airscrew
λ_0 = bending frequency of airscrew at rest
ϵ = hub length
S = static moment
θ = moment of inertia

} of the airscrew blade related to gripping axis.

Tests with different model propellers the self frequencies of which were computed with the methods described in the paper in relation to speed, resulted in the worst case in differences of less than 5 per cent. from the computed values. (The value $\epsilon S/\theta$ is introduced into the formula by an approximate consideration of the influence of the hub, which is taken as stiff, to the bending frequencies of the rotating airscrew. In the case of a linear reduction of the section, as usually with nearly all airscrews, $\epsilon S/\theta$ becomes simply $4\epsilon/l$, where l=blade length counted from the hub).

The value λ_0 of frequency of the airscrew at rest can best be taken from the test. In the D.V.L., the λ_0 values of real airscrews are found with scratch records described in the paper.

In several cases we could explain vibrations which occurred in flight by a resonance, the bending frequency of which was equal to two times speed (two disturbances per revolution, *i.e.*, with airscrew running before wings).

Occasionally designers computed the oscillations of their airscrews. The

[2] The method of computing is published in "Luftfahrt-Forschung," 7. Band, No. 3 (1930): F. Liebers, "Resonanzschwingungen von Luftschrauben." The report "Ueber Schwingungserscheinungen an Luftschrauben" (Zeitschrift für Flugtechnik and Motorluftschiffahrt 1931, No. 12, of Mr. Seewald gives a survey over the actual condition of research turned out by the DVL).

computation of oscillation on airscrews is in Germany neither generally usual nor necessary.

Statical Department.

(8) Mr. Walker asks about fatigue ruptures of wooden spars. The different behaviour of wooden spars in comparison with metal spars, according to the results already collected, leads to the conclusion that the fatigue strength of wooden spars when correctly constructed is equal to the fatigue strength of the unworked material. In metal spars we always found considerably lower average fatigue strength than that corresponding to the pure fatigue strength of the material measured on test specimens. The reason for this consists in local accumulation of strains arising from sudden changes of section, notches, holes, rivets, welds and defects of the material.[3]

(9) Replying to a question asked by Mr. Bairstow, the last alteration (from December, 1930) of number 9038 of the German (rules) for aeroplane construction gives information about the relation between the gustiness load (case G) and the flattening out (case A). According to this rule the gustiness factor to be used for strength calculation in the form of a load factor is:—

$$n_{ii} = 1 \pm (1/16) v_h w \eta (F/G) \quad (dc_a/d\alpha)$$

where

$v_h = m/s$ maximum horizontal speed
$w = m/s$ vertical air speed (gust)
$G/F = kg/m^2$ wing loading
$dc_a/d\alpha$ = variation of wing lift coefficient due to angle of attack (measured in arc).

η = factor in regard of the temporal variation of load due to the gust.

In the formula w is to be taken as 10 m/s.

Commercial aeroplanes possessing a greater ratio between maximum horizontal speed and landing speed than two, will probably have to be stressed according to the gust formula.

(10) I agree with the opinion of Mr. Lynam. However, we have to distinguish two causes in contemplating these *involuntary loads independent from the pilot*:

The gust loads with high factors which act seldom and which may be taken as quasi static, and the gust loads with low factors which so often occur that they bear the character of a dynamical load.

For the first kind of load, we agreed upon the rule 9038 already mentioned. We assumed vertical speeds of gusts upwards and downwards of 10 m/s for testing the static strength of wing. The size of the gustiness load factor to be regarded as acting in a dynamic manner is not yet definitely fixed. This load factor will prescribe the dynamic strength of the worked material, which will often be considerably below the dynamic strength of the unworked material because of the influence of notches, holes, rivets, welds, etc.). It will be necessary to carry out numerous flight-tests with many different types of aeroplanes above different types of ground in order to collect sufficient statistical material for the computing of load and safety factors with the aid of the theory of probabilities.

Probably a factor of 1 ± 0.3 or 1 ± 0.5 will be reasonable for the load factor for the dynamic gust load. For the alternating load, a certain safety difference from the dynamic strength of the worked material will have to be observed.

In many cases the choice of the sections will be in this way determined and not by the static or quasi static loads.

The influence of irregular time intervals between the dynamic gustiness loads will at the beginning be neglected. These time intervals probably do not

[3] The values measured by the DVL will be published in a report of Mr. H. Hertel "Dynamische Festigkeitsprüfung" (dynamic strength test) in the yearbook 1931 of the DVL.

cause an increase in the fatigue strains. The test flights mentioned above are to be carried out with aeroplanes really used in air traffic. The mounting of so great a measuring installation, as will be necessary for this research work, would be difficult with commercially used aeroplanes. Perhaps a little acceleration recorder mounted on each commercial aeroplane would be of great use, provided its record has been previously calibrated with respect to the wing loads.

(11). If I understand the question of Mr. Walker, he means that there must be differences between the accelerations computed from the stresses (elongations) measured at the wings and the accelerations measured in the fuselage. I agree to this opinion. The accelerations of the fuselage are on account of the elasticity of the whole aeroplane structure, especially the elasticity of wings, not identical with the accelerations of the mass of the wings.[4]

We think it will be necessary to carry out reliable research work concerning the stresses of aeroplanes in order to measure directly both the deflections of wings and their stresses (elongations) and the accelerations of the fuselage. For this problem we recently attached an optically recording accelerometer to a D.V.L. optograph. I refer here to the final remark of number 10.

(12) Mr. Lachmann is wholly in the right if he expresses the opinion that large aeroplanes may be subjected to loads of the same order as small aeroplanes, with respect to atmospherical disturbances. Therefore rule 9038 applies to aeroplanes of any size. I think it necessary to examine thoroughly the structure of gusts, especially the gust gradient.

(13) In reply to Mr. Handley Page, the greatest deceleration measured during our brake trials amounts to about 4 m/s^2 with the three-engined Junkers monoplane (G.24 type) without the machine nosing over.[5]

Engine Department.

(14) In reply to Sir Richard Glazebrook, the research work of Mr. Whiddington, of Leeds, is well known in Germany, especially his device for measuring the growth of plants.

With the D.V.L. method, however,[6] the tuning of two high frequency circuits is changed, while Whiddington uses the condenser for altering a tone of superposition. In this consists the fundamental difference between the two methods. The D.V.L. has not examined if the latter method can be used for internal combustion engines.

(15). Mr. Pye asked for the method of calibration concerning the measuring of pressure. The pressure scale is influenced by the changing thermal conditions, by changes of tension of the heating anode and the grid battery. It is not possible, therefore, to keep a constant pressure scale during a long time. After each set of measurements a fresh calibration is made. Thereby constant pressures of different values of compressed air in a container are recorded by the oscillograph. If the transmitter condenser or the cock between transmitter condenser and engine cylinder are water-cooled, the influence on the pressure scale will be lessened. But even with such an installation a pressure calibration must be carried out from time to time.

(16) Replying to Major Carter, damping coefficients have been computed from the torsiograms taken from engines having six cylinders in line and twelve

[4] I refer to the report being published in the yearbook 1931 of the DVL bei H. G. Küssner: "Beanspruchung von Flugzeugflügeln durch Böen" (Aeroplane wing load by gusts).

[5] The results of tests with DVL brakes will be published in the yearbook 1931 of the DVL by F. Michael: "Versuche mit Flugzeugbremsen" (tests with aeroplane brakes).

[6] The measuring installation for the recording of fast current pressure phenomena is described by Kurt Schnauffer in "Luftfahrt-Forschung" Vol. 6, pag. 126. . . . Kurt Schnauffer reports an application of this method for the exploring of knocking in Otto-cycle engines in "Zeitschr. des Vereines Deutschen Ingenieure," 1931, No. 15, pag. 451.

cylinders in two rows. Suppose the damping force to be proportional to the oscillatory speed ($D = k\,dx/dt$), the following damping coefficients were found:—

For engines with six cylinders in line: $k = 0.0008$ to 0.001 kg/cm² s/cm.

For engines with 12 cylinders in 2 rows: $k = 0.00016$ to 0.002 kg/cm² s/cm.

With these values it became possible to ascertain analytically the real oscillation amplitudes at resonance for engines of similar design, in satisfactory agreement with actual values.

For geared engines we found considerably greater damping factors. We are, however, at present unable to give you the corresponding values.

The assumption of a linear damping is advantageous because the calculation of the oscillations becomes simplified. Confirmation by torsiographical measurements could not be ascertained. On the contrary, the damping coefficients calculated on this assumption seems to be too small for great amplitudes and too great for small oscillation amplitudes. The real conditions in aircraft engines are much more complicated than can be incorporated by the assumption of a linear damping. In each case it is necessary to be cautious in the translation of damping coefficients to other engines.

Material Department.

(17). In reply to the question asked by Mr. Southwell, with the D.V.L. experiments on model crankshafts the oscillatory torque is generated electromagnetically by the oscillation generator of the Maschinenfabrik Augsburg—Nürnberg (MAN). This generator has no rotating part. In the engine box two pairs of electro-magnets are crosswise installed. Between these magnets a soft iron anchor is placed at 45°. The two pole pairs of the mass system are alternatively excited.

The control of the exciting current is effected by a pendulum switch fixed on the flywheel of the engine. The lever shown in the picture served for the generation of a superposed static torque with a weight load applied on long rubber cords.

(18) The laboratory tests carried out on ply-wood glued with Tegofoils[7] showed a much better resistance of this kind of ply-wood, in comparison with casein-glued ply-wood, against humidity and rotting. The glue strength (ascertained by shearing tests) showed some lessening with the Tegofoil glueing after being kept in water for 48 hours, while the casein glueing gave a much greater loss in strength. The strength and stiffness of the new kind of ply-wood are considerably better than the values measured on ply-wood glued in the usual manner. From these laboratory experiments, we believe this ply-wood to possess, besides a longer life, a better resistance against warping under atmospheric influences.

Electrotechnical and Wireless Department.

(19) In reply to Air Commodore Warrington-Morris, my statement that a special wireless operator might not be necessary on board did not mean that a wireless operator is not necessary, but that the wireless operation can be done by a W.T.-trained mechanic who will be necessary on board anyhow. In our German air traffic the combination of a mechanic and W.T. operator has proved quite satisfactory.

(20) During our experiments about the spreading of long waves, we chose a wave-length of 950m. instead of the international wave-length of 900m., being unwilling to interfere with the wireless communication of commercial aircraft. It can be proved that considerable differences in the spreading of both waves do not exist.

The objections expressed by Air Commodore Morris in regard of my statement that the present international wave-length is unfavourable are well founded.

[7] Furnished by Th. Goldschmidt A. G., Essen.

My statement may have been misinterpreted by the conciseness necessary in such a paper. I wished only to remark that in regard of the spreading over land an increase in wave-length would result in a greater range. The problem of the best international aircraft wave-length is so complicated that I did not intend to consider it in my short paper.

With reference to the value of a great range by long waves, the D.V.L. takes in general the point of view that one should aim at improving the range force for a given radiating power. The gain, however, should be used for lessening the sending power and so lowering the weight of the wireless apparatus.

(21) In reply to the remark of Air Commodore Morris about the value of a streamlined weight for improving the radiating qualities of a trailing antenna, I refer him to the report of the D.V.L. concerning the increase of effective height of aeroplane trailing aerials.[8]

(22) To the questions asked by Mr. Sinclair concerning the influence of the polarisation in regard of the spreading of long waves, the curves of diagram 51 are valid for trailing aerials. The influence of polarisation on the spreading has not yet been investigated for long waves.

The D.V.L. will issue a report on the service experiences with short waves.

Flight Department.

(23) I agree with Mr. Bairstow and with Mr. Walker about the importance of limiting elevator control. Any sudden zooming may be necessary in certain cases; for instance, during forced landing into small places. If the pilot has not the time to alter the trim of the aeroplane, it is possible that a machine fitted with limited elevator control would put its nose down. Under such circumstances any limiting of control will become dangerous. For some time now it has been necessary that German commercial aeroplanes should be capable of a good three-point landing, with the C.P. forward and the tail plane trimmed for cruising speed. For this reason there is a great difference between the tail-first design (" Ente ") and the conventional aeroplane.

(24) In reply to Mr. Bairstow, I have no doubt the autorotation of a wing cannot be avoided by twisting alone, but can be limited to certain ranges of the angle of attack. Further wind channel tests lead us to hope that it might be possible to prevent altogether any autorotation by giving the wing tip a symmetrical profile pierced in the manner of a lattice girder.[9] The aerodynamical quality of such a wing is poorer than that of a normal wing. I agree with Mr. Bairstow that up to the present it is doubtful if a wing can be made safe from autorotation without too great a loss of aerodynamical qualities.

(25) The usual method for dealing with spinning in Germany is to provide adequate control.

(26). In reply to Mr. Handley Page I refer him to a report about the flying qualities of the " Ente," which will be shortly published by Mr. Focke. The trials of this aeroplane are not yet complete. There will be a further report on the side fins used for improving the directional stability (" weathercock stability "), whether they should be reduced or totally suppressed. During the trial flights we found that the rudder control of the " Ente " is better than that of the average normal aeroplane used for similar purposes.

In conclusion, I hope that it will soon be possible for an English expert to give a similar summary of English research work before a German audience. I am convinced that such a paper will find a very attentive audience.

[8] See F. Eisner, G. Sudeck, R. Schröer and O. Zinke, Luftfahrt-Forschung, Vol. 8 (1930), pag. 141.

[9] These questions are treated by Wilhelm Schmidt in a paper which will soon be published about: Beitrag zur Entwicklung eines autorotationsfreien, steil landbaren Flugzeugs.

PROCEEDINGS

NINTH MEETING, SECOND HALF, 66TH SESSION

The last meeting of the 66th Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, May 14th, 1931, when a paper on "The Metalclad Airship," by Mr. Carl B. Fritsche (President, Aircraft Development Corporation, Detroit, Michigan, U.S.A.) was presented and discussed. The paper was illustrated with a cinematograph film, showing various stages of the construction of the first successful metalclad airship—the ZMC-2, of the U.S. Navy—and the ship in flight.

The President of the Society (Mr. C. R. Fairey, M.B.E., F.R.Ae.S.) was in the Chair.

The PRESIDENT: This paper was the last to be presented to a meeting of the Society in the 1930-31 Session, which Session had not lacked interest or variety, but it would be agreed that last was not least, and that the evening was likely to be one of the most interesting that the members of the Royal Aeronautical Society had enjoyed in the historic hall of the Royal Society of Arts.

The question of airships seemed always to be to the fore; it was always highly controversial, and always interesting. Parliament was debating the question that evening, and there had just been published the preliminary part of the Government's decision. It was learned, with some relief, that our airship policy was to be kept moving, even if construction were not continued. It might be expedient and necessary, from the Government's point of view, to suspend construction for the time being, but all concerned, and particularly the Royal Aeronautical Society, hoped very sincerely that that suspension was only temporary. Certainly other countries were not slowing up. The construction of large airships was proceeding in Germany and in America, but the policy of the past was to be altered in one important respect, in that these ships were to be helium-filled, whatever the type of construction—from which it would appear that the people responsible regarded the terrible disaster to the British Airship R101 as being due to the use of the wrong type of gas rather than the wrong type of apparatus.

The Royal Aeronautical Society existed to further every kind of aeronautical development, and during its long history every type of flying machine, which had ultimately been developed with success, had been derided as an impossibility. A feature common to critics of progress, no matter what type of apparatus they criticised, was that they seemed always to base their criticisms upon the contemporary performance of that apparatus, and to disregard the rapid advance that it was making. Sooner or later time found them at the mercy of the forces of progression.

The airship carried with it the burden of certain disadvantages, as did every form of apparatus, but the problems presented were often solved by people whose minds were not staled by long association with those problems, and who adopted boldly a new line of attack altogether. Rigid airships in the past had consisted of metallic frames, fabric covered, containing internal ballonets filled with gas; so that in effect each ship had two skins—one to contain the lifting gas and the other to maintain the streamline form. Obviously, this form of structure had resulted in a tremendous waste of cubic space, with corresponding loss of lift

for a given cross-sectional area. Then, some years ago, a proposal had been made in America, with a boldness which compelled admiration, that an airship should be constructed in a manner embodying the principles applied in submarines —having a metallic covering which would serve as the shell and as the gas container, this shell being supported by an internal structure, and working at a slight positive pressure. At first sight the proposal appeared to offer immense difficulties, in connection with both the construction and the use of the airship. The figures in the paper to be presented by Mr. Fritsche, however, showed how astoundingly successful the first attempt had been.

The Society was honoured by the presence of Mr. Carl B. Fritsche, the President of the Aircraft Development Corporation, which had built and tested this remarkable machine, and the members of the Society would hear from him personally the story of its development, which story would be illustrated by a cinematograph film. Mr. Fritsche, an engineer with a long and distinguished career, had founded the Aircraft Development Corporation in 1921. He was also Secretary of the Detroit Aviation Society and a Member of the Detroit Air Board, a Member of the National Aeronautical Association and of other bodies with similar interests in America. The Royal Aeronautical Society was very grateful to him for having travelled thousands of miles in order to present his paper.

Mr. Fritsche then presented his paper and film.

The PRESIDENT: On behalf of the Royal Aeronautical Society and of the visitors attending the meeting, he congratulated Mr. Fritsche very sincerely upon the success that had attended his work, and thanked him for the able manner in which he had described it. It was obvious that he had spared neither time nor trouble in the preparation of the paper, and it was very greatly appreciated. His work was destined to be an important milestone in the history of airship development, and the Society wished him good luck in his future work.

THE METALCLAD AIRSHIP

BY

CARL B. FRITSCHE[1]

President, Aircraft Development Corporation, Detroit, Michigan, U.S.A.

INTRODUCTION

An invitation to address the Royal Aeronautical Society, the first Society of its kind ever founded, is indeed a signal honour and not without misgivings to a humble visitor who, in the land of Elizabethan English, finds himself embarrassed for words adequate to express his appreciation.

The scientific contribution of the Society to the advancement of aeronautics and the meritorious achievements of its members are well known in the United States.

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[1] Member, American Society of Mechanical Engineers; Society of Automotive Engineers; National Aeronautic Association, U.S.A.; Detroit Aviation Society.
President, Aircraft Development Corporation, builders of first successful Metalclad Airship, ZMC-2.

Author's Note.—For cordial assistance in the preparation of this paper the author desires to acknowledge his indebtedness to Messrs. A. G. Schlosser, E. J. Hill, W. A. Klikoff, V. H. Pavlecka, and S. A. U. Rasmussen, of the Engineering Staff of the Aircraft Development Corporation, each of whom made a notable contribution to the building of the ZMC-2 Metalclad.

A sort of unselfish and patient willingness, which encourages men to depart from beaten paths and invade unknown realms to bring forth something new and beneficial to society, is indispensable to any new enterprise, and most characteristic of those who are pioneers in airship development. Certainly none so far have garnered any substantial profits.

But it is no reflection upon their intelligence if they have the fortitude to carry on the task, triumphant over the normal instinct for immediate profit. "Intelligence always stretches forth welcoming arms toward the new and little known, while instinct wraps its legs around the venerable and tried, and endeavours not to budge."

Frankly, it is contrary to the instinct of man to fly.

This is the most stubborn obstacle that confronts the aircraft pioneer. In fact, it is uncertain which is the more wonderful, that man conquered the air or that he ventured to fly. However, it is not too optimistic to believe that the generation now approaching maturity will experience a "triumph of mind over matter" that will confound this adverse instinct.

Martyrs to Science

Honour will then come to those who have shown the way. Man will realise that those martyrs who passed on with the R.101 and the R.38 did not die in vain.

Many of their co-adventurers in other countries have also been the victims of tragedy, which always takes its toll along new frontiers of science. The sacrifice of brave and talented men which attended the early Zeppelins, the Roma, the Dixmude, the Italia and the Shenandoah, is indelibly imprinted upon the pages of history. On each occasion the world at large has said that man has gone too far in daring exploration. So it is well not to forget that invention has always to convince sceptics.

It is not characteristic of mankind to give up in the face of temporary defeat. Research and experiment broadening the horizons of knowledge must continue. The final victory is a monument to the fallen no less than to those who have triumphed. Their sacrifice is a living challenge to carry on the task they have regretfully laid down until ultimate success is realised.

England's Contribution

Airship development and operation in England, no less than in Germany, has been a source of constant inspiration and friendly encouragement to those of us engaged in similar undertakings in the United States.

One can never forget that in 1919 a British airship, manned by a British crew, under the command of the late Major G. Herbert Scott, distinguished itself by making the first trans-Atlantic non-stop flight in any kind of aircraft from England to New York and return without a mishap. This celebrated voyage of the R.34 startled the world, and while perhaps it did not receive as much acclaim as have some of the more recent airplane flights, still its place in history will be just as secure from the standpoint of pointing the way to the eventual and practical commercial conquest of the Atlantic.

In the opinion of many, the courage and determination that marked this adventure of the R.34 is comparable to the celebrated voyages of Columbus and Magellan, with the possible exception that the romance attending the discovery of new land was lacking. However, Scott did explore a new ocean that encompasses the entire world, an ocean that serves every port.

Nor can one forget the summer of 1930 when the R.100, with its distinguished crew, duplicated the record of the R.34 in successfully negotiating a trans-Atlantic voyage, this time from England to Canada and return, thus rewarding the creative genius of Commander Burney, Mr. B. N. Wallis and their associates.

Those who accorded her a thunderous welcome visioned the day when scores of larger majestic ships of the air would encircle the globe, promoting mutual benefit and understanding. The minor mishaps which accompanied her flight did not subtract from her triumph. These misfortunes, as well as the tragic disaster to the R.101, are only reassuring evidence of the fact that the limit of human intelligence has not yet been reached. They serve to remind one of President Hoover's tribute to Thomas A. Edison at the celebration of the fiftieth anniversary of the invention of the electric light. The President said in part:

> " I may emphasise that both scientific discovery and its practical application are the products of long and arduous research. Discovery and invention do not spring full grown from the brains of men. The labour of a host of men, great laboratories, long, patient, scientific experiment build up the structure of knowledge, not stone by stone, but particle by particle. This adding of fact to fact some day brings forth a revolutionary discovery, an illuminating hypothesis, a great generalisation, or a practical invention."

Scott's Mooring Mast

England has made many noteworthy contributions to the art of airship design and operation. Unquestionably the mechanical handling of airships, and particularly the mooring mast, an innovation resulting principally from the inventive genius of the late Major Scott, constitute a major contribution to the art.

More recently, the incorporation of steel in the main structure, the introduction of deep transverse frames independent of radial wiring, and the pioneering development and use of oil-burning engines in the R.101, as well as the novel tubular construction of girders in the R.100, all have excited most unusual interest.

Refinement of contour of design in favour of a smaller fineness ratio, improved methods of operation, the invention of delicate instruments essential to precise navigation and control, exhaustive wind tunnel studies and a world-wide investigation of meteorology as it relates to airship operation, all come in for praise.

But the progressive accomplishment that excites one's imagination most is the actual construction, in strategic locations throughout the Empire, of modern airship bases for commercial utilisation. And when one turns to the Air Annual of the British Empire for 1930, he finds a map on which are delineated in bold lines projected British Airship Routes connecting the old world with the new, and circumnavigating every continent in the Eastern Hemisphere except northern Asia.

Certainly a people responsible for such a bold and ambitious programme are not pessimistic about the future of airships. Their intelligence has triumphed over instinct. Their courage and vision are defiant as the inspiring challenge hurled by a renowned philosopher of ancient Greece to those who questioned his idealism:—

> " *In a just cause it is right to be confident.*"

So one finds here a sympathetic atmosphere created by friendly contemporaries who apprehend the essence and reality of things in opposition to those who depend on mere appearance and sensation.

In a spirit of co-operation one comes here to give and to take away. If competition exists—excellent—for it would be unhealthy otherwise. Spencer once said, " Heat is made by drawing things together, and after a while, when you have heat, you have light also."

So if debate is to follow, may it become quite heated in order that the light which brings truthful understanding may prevail. For truth flows freely from the mind when it feels the friction of debate. Without competition nothing approaches perfection.

It has been said that engineers tame the forces of Nature to make life easier for mankind. But there is no law of Nature to the effect that what is *not* contained in the text book must be untrue. Under such a situation science would be abolished and dogmatism substituted.

By far the greatest and most sinister obstacle engineers encounter is the human mind itself. It distrusts, hinders and even ridicules their efforts, only to accept them for its own in the end.

Indeed, the engineer's task would be simple and pleasant if he had to contend with Nature only. But the limiting factor of human behaviour makes his ordeal sometimes a bitter one.

Now every great scientific development has come many times to the cross-roads of doubt at which people have stood unequally divided, most of them wanting to turn back and few wanting to go ahead. This is often the characteristic of human behaviour. The disaster to the R.101 has brought people's minds to one of these cross-roads. And again the burden of proof is thrust upon the engineer.

Historical Reference

So in addressing the Royal Aeronautical Society on the metalclad airship it is comfortable to know that one can quote from eminent English authorities. Of outstanding interest is the following excerpt from the late Colonel Richmond's last scientific address delivered before the British Association for the Advancement of Science at Bristol, England, September 8th, 1930:—

> "Filled with helium, driven by engines burning heavy oil fuel and sheathed in metal, there is no reason why the airship should not become the safest form of transport yet devised."

Of equal interest is the statement contained in the response made by the late Major Scott at the public reception accorded the officers and crew of the R.100 at Montreal, Canada, August 2nd, 1930:—

> "The fabric covering still presents the most serious problem in airship construction and operation."

And contemporaneously is the conviction expressed in a letter of October 18th, 1930, received from Sir C. Dennistoun Burney:—

> "I feel that until we get away from all this fabric work we shall never get a first-class vessel."

It is believed this prophecy of Colonel Richmond's will come true. The construction of a successful "metal-sheathed" airship, the ZMC-2, has already been accomplished. The location of ample helium deposits in the United States is well known and the cost of production is decreasing each year. That additional discoveries of helium elsewhere will duplicate the history of petroleum is a foregone conclusion.

With respect to heavy-oil-burning engines, some eight or ten experimental developments now in progress in England, Germany, France, Italy and the United States justify the hope that one or more dependable high-powered engines of this type, sufficiently light in weight, will soon be available.

With such an airship, built according to the ideal specifications outlined by Colonel Richmond, the danger of fire or explosion will be absolutely abolished; freedom from danger of lightning will be analogous to that of the steel steamship; structural safety factors will be increased; and a speed in excess of 100 miles per hour will be practicable. With the metal covering there will be no bursting gas chambers; diffusion of helium will be reduced one-half, thus limiting operating charges from this source to a reasonable figure; and mooring out of doors under all but the most extreme conditions will be feasible with no fear of deterioration from the actinic rays of the sun in the tropics. Then the truly commercial airship will have arrived.

Schwartz's Airship

Men will pause again to pay tribute to David Schwartz and Count Ferdinand Zeppelin and their successors. Although Schwartz, an Austrian, never lived to realise his dreams, he gave to the world its first rigid airship and it was a metal-clad built in Berlin and covered with very thin aluminium. It was a small ship, being only 135 feet long and having a diameter of 45 feet. Schwartz died just before it was ready for inflation, but his faithful wife continued the work, engaging Jagels Platz to act as its pilot.

In its first flight, November 3rd, 1897, the driving belts slipped off their pulleys on the crude engine and the powerless craft, with one man on board, was carried by the wind to a forced landing in a forest. The ship was badly damaged and was soon dismantled by curio-seekers and the task passed on to succeeding generations having available better engines, stronger aluminium alloys and a higher degree of technical skill.

Soon the advent of the automobile brought with it the necessity for finer metals, more perfect alloys and better motors. Later, the four years of the World War (1914-1918) spurred metallurgists of every civilised country to greater endeavours during that period. Governments literally poured money into all phases of aeronautic development and thereby brought about a remarkable advance in the new art of flight. Each domain of science made its contribution. With the return of peace the time was ripe for the next logical step.

Ten Years of Research

In the early stages of any new development the soundness of the scientific principles involved, rather than the choice of materials used, receives the most emphasis. Witness that Count Zeppelin, who purchased Schwartz's patents, immediately discarded aluminium covering for the more easily procurable fabric. In following the line of least resistance he was perfectly right. It was too early for the metal ship. Fundamental principles and demonstration always take precedence over refinement of materials and design during the experimental stage.

After the feasibility of a scheme has been proved, the next step is the introduction of better materials and refinement of design in order to gain greater efficiency. The airship has now reached this stage.

Durability, cost of upkeep, strength and weight combination and economy in operation are certainly some of the primary factors that now must be considered. They may have been of minor importance during the early stages of development, but they become dominating ones under commercial conditions. Certain materials, such as fabrics, complex systems of wiring, etc., which have variable strength, deteriorate rapidly or are easily damaged, should certainly be replaced by others possessing the qualities previously mentioned.

Even the ordinary citizen recognises this fundamental fact in the things he uses in everyday life. One has only to mention the substitution of metal for wood in railway cars, steamships, bridges, automobiles, etc., and gradually the same substitution for fabrics, dope, wood and wires in airplanes, to realise the validity of the argument.

So in 1921 a group of men in Detroit, identified principally with the automotive industry, encouraged by the availability of dependable engines, of light thin alloys and of more seasoned engineering talent, organised an experimental airship engineering group, headed by Ralph H. Upson[2] and the speaker. Their purpose was to modernise the rigid airship and make it all metal like the hull of the sea-going vessel.

It appeared obvious to them as laymen that if a substantial metal covering could be substituted for the cotton fabric covering used in the conventional rigid

[2] F.R.Ae.S., Chief Designer of ZMC-2, Professor Aeronautical Engineering, University of Michigan; awarded Wright Brothers Medal, 1930.

airship, the superiority of this new type construction would be as great as that of the iron steamship over the old wooden clipper ships. It was realised that the principal handicap to overcome would be the excess in weight of the metal hull covering, and that the extent of this handicap would be determined by the minimum thickness of the aluminium alloy sheet it would be practicable to produce, fabricate and assemble.

The first endeavour of this experimental engineering group in Detroit was to isolate and to determine the scientific fundamentals governing the design of an all-metal structure in airships. The General Motors Corporation,[3] the Ford Motor Company, and other industrial concerns very generously contributed valuable laboratory facilities; the Aluminium Company of America undertook to develop aluminium alloy in thin sheets; aeronautical engineers and metallurgists in Washington were invited to offer criticisms and suggestions, and thus through sound, laborious and painstaking engineering methods they set about the development of a safe and practicable metalclad airship.

It was soon realised that the thinness of aluminium alloy sheet available would determine only the minimum size airship it would be feasible to build, but would have no influence on the maximum size of airship, because as the size increased the thickness of the hull covering would increase also, but to a lesser extent, thus reducing the weight handicap as well as simplifying the problems of fabrication and assembly.

The logical deduction from these premises suggests the following conclusion :—

> " As metalclad airships increase in size, the difficulties of design, fabrication and construction decrease proportionately."

In the course of the metalclad development hypothetical metal ships of different sizes were designed in considerable detail and a thorough stress analysis involving even the integration of all forces as applied to each square foot of the hull surface was worked out carefully. No experimental effort was spared through actual physical test to verify the theory of design, of the main bending and shearing action and of the safety factors involved. So gradually through years of patient and systematic effort the general theory of the metalclad airship was mathematically and experimentally proved.

Fundamental Design Varies from Zeppelin Practice

For ten years this engineering research and investigation has been carried on. The trial and error methods disclosed that, while the Zeppelin development is extremely valuable from the standpoint of the definition of technical problems, the methods of solution are in most cases different. This is due to the fact that the entire theory of the accommodation of stresses in the metalclad ship is different from Zeppelin practice. In the metalclad ship the shear stresses, and to a large extent the tensile stresses, are carried in the metal covering, the plating of which also very definitely reinforces the internal frame members, thus reducing their design weight requirements. In the Zeppelin the shear stresses are carried through a complex system of diagonal wiring in the planes of the ship's surface. The fabric covering serves mainly to fair the surface and to resist the outer air pressure in flight.

To illustrate more fully, let us examine the physical structure of the two different types. The surface of the conventional fabric ship consists of five layers (exclusive of framing), from outside to inside, namely :—

---

[3] Through the co-operation of Mr. C. F. Kettering, Director, General Motors Research Laboratories, and Mr. W. B. Mayo, Chief Engineer of Ford Motor Company (both of whom are members of the Technical Committee of Aircraft Development Corporation).

Outer fabric covered with doped coating.
Shear wiring.
Gas pressure wiring.
Cord netting (eliminated in the latest Zeppelin).
Gas cell fabric lined with goldbeater skin.

These five layers in the fabric-covered airship collectively perform the function of :—

Fairing the surface.
Protection against atmosphere.
Transmission of shear stresses.
Accommodation of pressure.
Retention of buoyant gas.

The single metal surface in the metalclad ship performs all these functions and performs each of them in a better way. In the fabric ship the rigid frame members receive no substantial support from the fabric due to its varying tension with change in weather conditions.

The metalclad ship is a single structural unit in which the surface plating carries a considerable portion of the direct stresses. The metal plating, which is the outer cover, is the principal strength member and is also the gas container.

There are no indeterminate stresses resulting from the varying tension of radial wiring, shear wiring and gas pressure wiring.

Metalclad Similar to Submarine

Dr. William Hovgaard,[4] Professor of Naval Design and Construction, Massachusetts Institute of Technology, and a member of the British Institution of Naval Architects, comments as follows on the simplicity of the metalclad and its analogy to the submarine :—

> " The metal skin plays about the same part as in the strength hull of a submarine, where the shell plating forms at once a water-tight envelope for the inner hull capable of standing pressures and a girder as well. This feature, together with the internal structure, serves to resist longitudinal bending and transverse shearing.
>
> " The metallic skin in conjunction with the rigid main frames and a high gas pressure insure a maintenance of form not obtainable in the Zeppelin type where the diagonals permit very great shearing deflections.
>
> " The conventional bending theory which is used in calculating the longitudinal and shearing stresses applies with greater accuracy to the metalclad than to the Zeppelin type so long as the air pressure is maintained as assumed. The fact that a high internal pressure can be safely maintained is one of the most important advantages of the metalclad. Associated with a rigid structure, the metalclad skin places this new type of airship in a class by itself, superior in strength and stiffness to all former rigid and non-rigid airships. It excels by its simplicity."

Metalclad Ideal for Economic Use of Materials

In other words the problem of building a metalclad airship, as in a submarine, involves primarily the economic disposition of materials. This fact is emphasised by Dr. Herbert C. Sadler,[5] Dean of Engineering, University of Michigan, Professor of Naval Architecture and Marine Engineering :—

[4] Also Consulting Engineer to the U.S. Navy on Submarine and Airship Design.
[5] Also Consulting Engineer to the U.S. Shipping Board.

"A fundamental factor which tends toward the most economic solution of a problem, is the disposition of materials of construction so that if possible they may perform more than one useful function. From time immemorial, this has been a recognised fact in ship construction, where the hull of the ship is designed not only to give the necessary strength to the structure, but also to keep the water out and give the proper outside shape to fulfil the conditions of speed and carrying capacity.

"In the case of an airship, the same philosophy is sound, in that from aerodynamic conditions we must have a certain form or shape, a certain strength of structure, and at the same time a certain volume to be filled by a gas which will give the proper buoyancy to the whole.

"Are the following questions not proper ones to ask: Why should the construction of the airship, so far as its strength is concerned, be considered as an item by itself? Why, to get the proper shape outside, should more material of very questionable durability be added? And why should still more material of still less durability be added to the inside in the shape of balloons to hold the gas? Should not the outer covering be made of metal and so help to form a valuable addition to the strength of the structure and at the same time be moulded to the proper shape, and also act as a container for the gas? From the point of view of the scientist, engineer and operator, there is only one answer to the last question—Yes.

"It is a matter of common knowledge that a circular-shaped structure with metal disposed on the circumference is the lightest form from the strength point of view. The metalclad airship takes advantage of this accepted fact."

Excess Weight Handicap Disappears with Size

The major problems of metalclad design and construction investigated were: The problems of weight; method of erection; method of joining sheets; methods of attaining gas tightness; corrosion of the thin hull plating; fatigue of the metal plating under vibration, and its effect upon the gas tightness of the seam. Each of these problems was taken up in turn and solved and thoroughly tested in the laboratory before any actual construction was considered.

A study of weights of metalclad construction showed that for large sizes of moderate speeds the weights of a fabric-covered ship should be equalled, and that for large sizes of high speeds (100 m.p.h. and over) the metalclad held promise of being superior to the fabric-covered ship, particularly from a weight consideration.

It was decided that the hull could best be erected vertically in sections. Using this method it was logical to assemble the hull plating from a series of transverse rings, which, in the vertical position, were then parallel to the floor. The hull sections, being suspended from the hangar roof, could be raised and the successive transverse rings assembled from the floor, raising the section with the addition of each ring. After assembling a section of hull plating the internal framing could be expanded tightly into place and riveted to the plating. When each section was completed it could be turned into the horizontal position and the various sections joined together to form the complete hull. This method was executed in the construction of the first experimental metalclad substantially as dictated by early engineering study and proved a practical method of construction.

Automatic Riveting Machine

The joining of the thin sheets of hull plating, it was decided, could best be done by riveting. An automatic riveting machine was developed employing a new principle in riveting, a remarkable achievement and an economic necessity in the construction of large size metalclad airships.

In its operation three strands of wire are fed like thread into the machine and three rows of rivets are "sewed" simultaneously. The machine shears off the wire, rivet length. The tiny wire sections are punched through the two sheets of metal and the revolving cams head up the rivets. The spacing of rivets is also automatic. With this riveting machine two men are able to

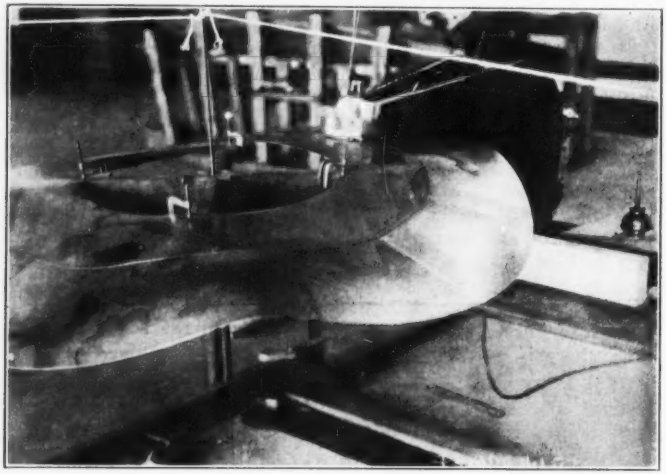

FIG. 1.
Beginning of first stage of construction of metalclad ZMC2. Riveting machine sewing first hull plates of bow cap.

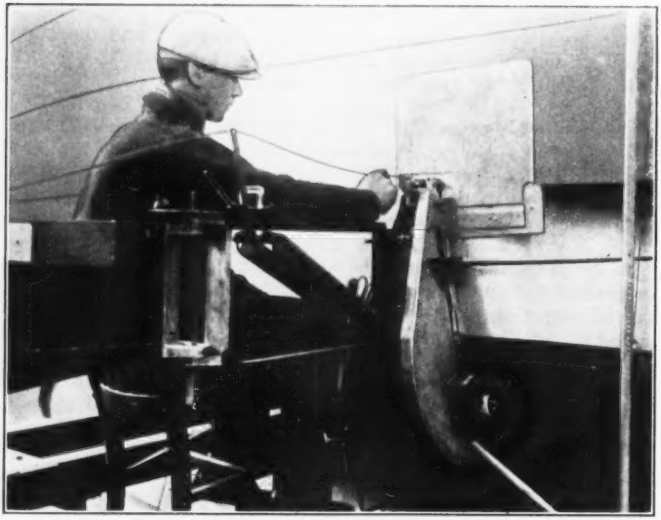

FIG. 2.
Close up of automatic riveting machine. Capacity 5,000 rivets per hour

accomplish as much work in a given time as 128 men working by hand. It inserts and completes 135 rivets per minute, or about 5,000 rivets per hour. This machine successfully drove about 3,500,000 rivets of .035in. diameter in the hull of the first experimental airship with only one-third of one per cent. defective rivets.

Gastight Seams Developed

After the perfection of the riveted seam it was necessary to find a satisfactory sealing compound to seal the seam gastight. Such a compound with a bitumastic base was finally developed and laboratory tests indicated a permeability less than other buoyant gas containers.

During this initial period of investigation and development, the best material available was thought to be plain duralumin. Exposure tests were conducted to determine its resistance to corrosion and various protective coatings were investigated. At the time of starting actual construction of the first experimental metalclad, plain duralumin treated by the anodic process was selected as the best material from the standpoint of resistance to corrosion.

The thin duralumin sheets and riveted seams were tested to determine the effect of vibration and snap diaphragm action. By a specially designed machine the specimens were subjected to millions of continuous vibrations at high speed, and the conclusion arrived at was that any fatigue of the metal and seams, due to snap diaphragm action, was a very remote possibility.

This exhaustive research occupied seven years prior to the actual construction of the ZMC-2 and has continued without interruption ever since. Certain definite conclusions, related particularly to the commercial application of large metalclads, are discussed in succeeding chapters.

First Successful Metalclad, ZMC-2[6]

Visionary opinions having been replaced by scientific facts to an unprecedented degree of completeness, in 1928 the actual construction of the metal hull of the ZMC-2, as it now exists, was begun. The first rivet was driven in the bow section on March 7th of that year, and on August 10th of the following year the ship was completed, inflated with helium, and ready for trial flights. The substitution of alclad sheet for duralumin in the hull covering is explained later.

The internal structure[7] of the ZMC-2 hull is composed of 24 equally spaced longitudinals and 12 circular frames which are riveted to the outer cover of alclad sheet .0095 inches thick. Five of the transverse frames are of built-up type heavy girders, braced with wiring in their own planes. These frames carry all concentrated loads due to handling lines, weight of car, engines, fin loads, landing loads, etc. The rest of the structure is built of very light sections primarily designed to maintain the shape of the hull and support the outer cover when the ship is deflated. Three air valves and two gas valves are used, as well as several manholes to provide accessibility to the gas chamber. Handling lines are attached to the fittings on the main wire-braced frames.

The car or control cabin is suspended from two main frames near the maximum diameter of the hull. It is 24 feet long and 6.5 feet wide at the maximum section. The structure consists of eight transverse frames and

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[6] Acknowledgment is gratefully expressed for the unfailing co-operation of the Bureau of Aeronautics of the U.S. Navy, for whom the ship was built, and to various members of the personnel of the National Advisory Committee for Aeronautics and of the Bureau of Standards, who extended invaluable scientific aid.

[7] More complete description contained in "Aircraft Engineering," London, Vol. II., No. 6, June, 1930, page 148; and in "Transactions of A.S.M.E." Aer., Vol. 51, January-April, 1930, pages 245-266.

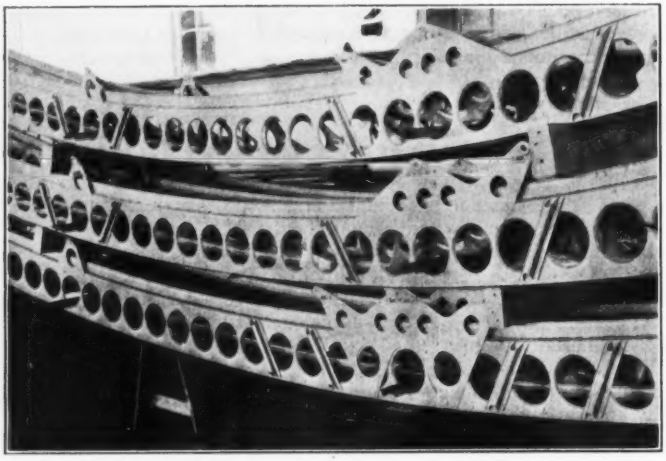

FIG. 3.

Segments of internal transverse frame members of ZMC2. In a large commercial metalclad these transverse frames would be about eight feet deep.

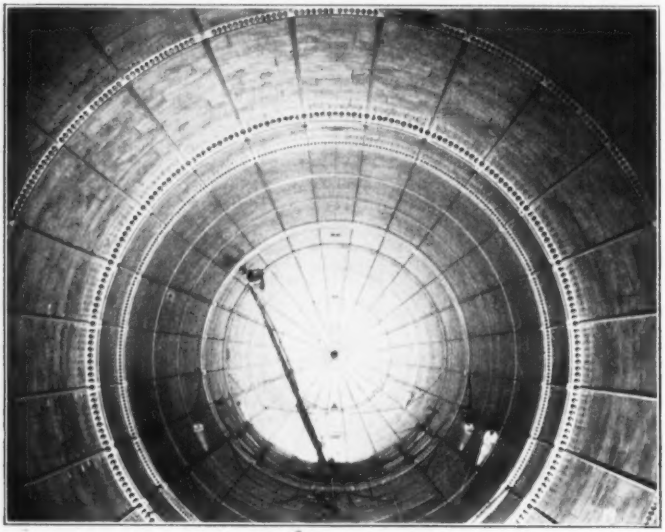

FIG. 4.

Interior view of ZMC2. Note men standing on metal plating.

several longitudinals braced by diagonals and covered with .014 inch corrugated alclad sheet. Two 220 h.p. Wright Whirlwind engines are suspended from the car by tubular outriggers. The bow of the car is occupied by the pilots, navigation and radio equipment, while in the stern are disposed the gasoline and ballast tanks. The total fuel capacity is 250 gallons. The mechanic's controls, instruments and seat are placed in the middle, and the landing gear is attached to the bottom of the car. A handling rail is provided on each side for ground handling by the landing crew.

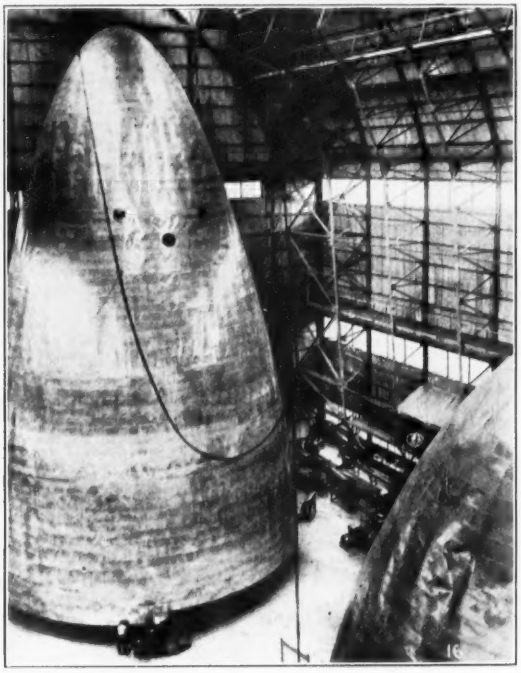

FIG. 5.

Vertical method of erection.
Automatic riveting machine in foreground travelling on track around half section of ship.

Two ballonets, made of two-ply rubberised fabric, are located inside the hull, forward and aft of the car. The ballonets are inter-connected by a duct system, into which air is supplied by scoops. One dynamic scoop is located at the forward end of the car and two propeller scoops on the outriggers. An auxiliary hand operated blower is also provided in the car to maintain pressure during ground handling.

Fins

Instead of the conventional four-fin arrangement, the ship is equipped with eight fins equally placed around the circumference, four of them acting as vertical

surfaces and the other four as horizontal surfaces. This arrangement of fins allows a higher aspect ratio than is customary, thus giving unprecedented efficiency to the fin group as a whole. The fins are mounted to two hull frames and are braced by streamline wires. To the trailing edge of the fins are attached movable control surfaces, which are operated by cables running to the car. The structure of the fins is covered with corrugated alclad sheet of an average thickness of .008 inches.

The general characteristics and perfomance data of the ZMC-2 airship are given in the following tables.

TABLE I.

GENERAL CHARACTERISTICS OF THE ZMC-2 METALCLAD.

Length of Hull	149ft. 5in.
Diameter of Hull (max.)	52ft. 8in.
Fineness Ratio	2.83
Displacement of Hull	202,200 cu. ft.
Total Ballonet Displacement	50,600 cu. ft.
Front Ballonet Displacement	22,600 cu. ft.
Rear Ballonet Displacement	28,000 cu. ft.
Ratio of Ballonet Volume to Hull Volume	25%
Thickness of Skin	0.0095in.
Length of Car	24ft.
Width of Car	6ft. 6in.
Number of Air Valves	3
Number of Gas Valves	2
Number of Fins	8
Total Fin Area	440 sq. ft.
Total Elevator Area	190 sq. ft.
Total Rudder Area	95 sq. ft.
Total Automatic Rudder Area	95 sq. ft.
Engines (Wright Whirlwind J-5)	2
Power at 1,800 r.p.m.	440 h.p.
Propeller Diameter (all metal)	9ft. 2in.
Lineal Feet of Seam	17,600ft.
Surface Area	19,436 sq. ft.

TABLE II.

PERFORMANCE DATA OF THE ZMC-2 METALCLAD.

Gross lift (100 per cent. inflation with 92 per cent. pure helium at 60 deg. Fahr. and 29.92 in. Hg.)		12,242 lb.
Weight Empty		9,115lb.
Useful Load		3,127lb.
Crew (three)	600 lb.	
Fuel (200 gal.)	1,200 lb.	
Oil (25 gal.)	200 lb.	
Ballast (50 gal.)	420 lb.	
Passengers and Cargo	707 lb.	
Range with 250 gal. (Cruising Speed)		760 mi.
Maximum Possible Range (still air)		1,120 mi.
Maximum Speed at 440 h.p.		70 m.p.h.
Cruising Speed at 220 h.p.		56 m.p.h.
Static Ceiling		9,000ft.

Alclad Substituted for Duralumin

The original specifications of the ZMC-2 provided for a hull covering of plain duralumin[8] .008 inches thick. It was the first time that sheet of this thickness had been rolled in commercial sizes, consequently its resistance to corrosion was not definitely known. Through the co-operation of the British Air Ministry the anodic process developed in England was made available, and the sheet metal was given this treatment. When the hull of the ship was one-fourth completed, exposure tests conducted by the Bureau of Standards had progressed to the point where an appraisal could be made of corrosion and embrittlement of the material.

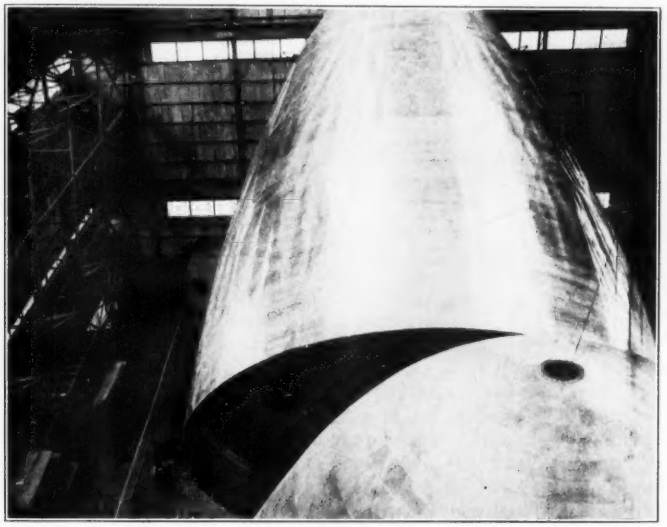

FIG. 6.

Swinging two halves of ship to horizontal position for final assembly.

Six months' exposure revealed that a serious deterioration resulting from inter-crystalline attack had occurred, the tensile strength, 60,000lb./in.^{2}, dropping to 50,000lb./in.^{2} and the elongation, originally 15 per cent., diminishing to four per cent. It was evident that this was not a safe material with which to proceed, so construction was temporarily halted. It was concluded, however, that the failure was due to the thinness of the sheet and was not attributable to the anodic process, its value for certain protective purposes having been previously demonstrated with relatively thicker gauges of metal.

Fortunately, the development and testing of "Alclad" 17St Alloy by the Aluminium Company of America[9] had progressed to a point where its superior resistance to inter-crystalline corrosion might be accepted as an assured fact. "Alclad" might be described as a "duralumin sandwich," the meat or core being plain duralumin coated on each side with pure aluminium. Theoretically, the pure aluminium is electro-negative to the aluminium alloy, and in the case

[8] Aluminium Company of America 17 St.

[9] Scientific contribution of E. H. Dix, Jr., and C. F. Nagel, of Aluminium Company of America, and of Dr. E. Blough, Chief of Research, Aluminium, Limited.

of galvanic action acts as a barrier to corrosion of the core. The aluminium coating thus serves as a guard against corrosion, similar to the action of zinc on steel. In view of the obvious advantages of this new metal, it was decided to scrap the partially completed hull and start over again, substituting .0095 " Alclad " for .008 duralumin.

Full Size Section of Hull Tested

Incidentally, this gave an opportunity to test the discarded stern to destruction in order to prove design theories with a full size section 29 feet high and 34 feet in diameter and weighing about 400lbs. The lower edge of the vertical section was embedded in a concrete ring weighing 56,000lbs. and made airtight by a water seal at the bottom. It was then inflated with hydrogen and tested for gas tightness. Samples of gas, to determine its purity, taken at intervals and at different places on the hull, an external soap film test and the use of leak detectors, all confirmed the theoretical gas tightness beyond expectations.

One of the most interesting features of the test was the behaviour of the stern section with internal pressure reduced to approximately .3 inches below atmospheric. Hydrogen was first displaced with air, for safety purposes, and artificial suction created. Naturally the sheet metal folded in between the longitudinals, producing long wrinkles. The longitudinals straightened out, losing their convexity between transverse frames. Many of the folds of the plating were so sharp that it seemed the metal was permanently distorted and that reintroduction of pressure in order to restore the plating to its original contour would cause a fracture or failure. On the contrary, when the pressure was again raised to 2in. H_2O above atmospheric, the shape of the stern was so perfectly restored that it was almost impossible to ascertain where the buckles had occurred.

During this experiment some of the longitudinals were found to have been broken by the bending moment to which they had been subjected, while the section was under suction. In his report on this punishing test, C. P. Burgess[10] emphasised the fact that the behaviour of the structure as a whole indicated that although some of the longitudinals failed, the stressed skin evidently was very effective in supporting the internal structure against complete collapse and failure. This is another most desirable advantage of the monocoque self-contained structure of the metalclad that cannot be too highly valued.

Next the hull section was subjected to a distributed side load of 2,650 pounds, thus approximating a condition of bending in excess of that occurring in the actual ship. The interior pressure was varied from −0.3 inches of water to +13.0 inches of water, and the test indicated a longitudinal stress safety factor of 9. At the high pressure of +13.0 inches, the 400lb. section actually lifted the 56,000lb. concrete ring from the floor, breaking the water seal, thus releasing the compressed air with a sudden rush. This was considered a most remarkable demonstration of superior strength and enabled the builders of the ZMC-2 to proceed with its construction with utmost confidence.

Completed Ship

The completion and trial flights in August, 1929, demonstrated the soundness of the theories involved in the ZMC-2. This novel ship when completed was actually 127 pounds under contract weights. It fulfilled every contract requirement on the first attempt with a safe margin over. Under maximum adverse conditions, combined with internal pressure of 4 inches of water, the factor of

[10] Aeronautical Engineer, U.S. Navy; R.Ae.S. commended R.38 Memorial Prize Paper submitted in 1923 jointly by Mr. Burgess, Comdr. J. C. Hunsaker, U.S.N., and Mr. Starr Truscott on " The Strength of Rigid Airships."

safety of the hull plating in the longitudinal direction is over 10 and in the transverse direction is 5.0. The smallest factor of safety in the girders is 4.7. These high safety factors were dictated by the minimum thickness of sheet metal available, which is out of proportion to the small size of this ship.

Helium Diffusion Low

Measurement of the diffusion during the trial flights of the ZMC-2 indicated an average loss of about 200 cubic feet of helium per 24 hours. In lift this

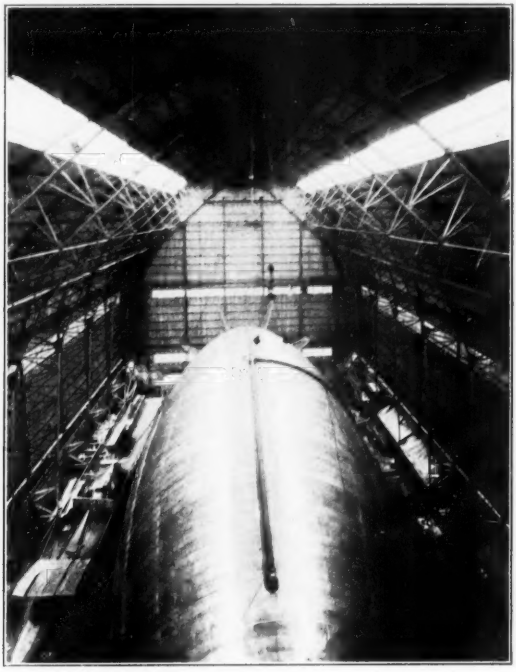

FIG. 7.
Completion of final assembly and inflation with helium.

represents 12 pounds loss and, applied to the surface area, it represents 3 litres per square metre per 24 hours. At the present time, after over 500 hours of flight operation and two years after the completion of the ZMC-2 hull, the Navy log book shows an average daily loss in lift of about 16 pounds. This is equivalent to a loss of 258 cubic feet of helium and in area represents a diffusion of about 4.0 litres per square metre per 24 hours, or the equivalent of aged goldbeater skin.

It is believed to be a fair assumption that at least one-half this leakage is due to valves and the fabric envelope of the ballonets. The fact that the ZMC-2 is used for training and for experimental purposes aggravates the loss of helium also. Therefore, in view of this assumption it is submitted that a fair estimate of diffusion through seams of the two-year-old metal is from 1.0 to 2.0 litres per square metre per 24 hours, or an average of 10 pounds per 1,000ft.[3]

per annum. This represents an annual loss of only 16 per cent. of the total lift of the ship.

It should be emphasised that in a large metalclad of commercial size the rate of diffusion would decrease for several reasons. The valves and accessories would be relatively lower in number and larger in size. New material showing marked improvement over rubberised fabric in gas tightness is now available and would be used for ballonets. But most important of all, in the larger sizes of ships the ratio of hull area to total volume decreases and likewise the ratio of total length of seams to hull area decreases still more, inasmuch as thicker sheets are rolled in greater width. This reduces the area of critical exposure, thus again reducing the loss of helium.

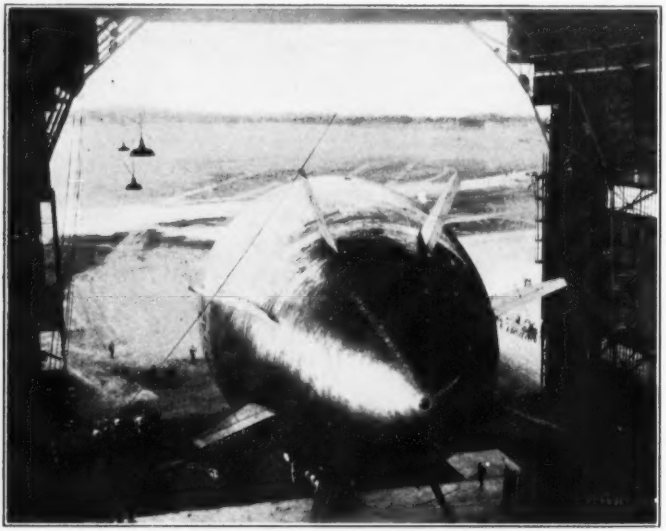

FIG. 8.
View of stern of ZMC2 showing eight fins.

Intercrystalline Corrosion

Returning to the specific subject of corrosion. The alclad covering of the ZMC-2 is now almost three years old. Superficially the exterior of the hull appears less bright in lustre, due to a film of oxide on the pure aluminium coating. The interior, being in direct contact with helium, of course, is relatively free from oxidation and has the same mirror-like brilliance that characterised the metal when new.

Last December (1930) four plates, 10in. by 12in., were cut from the hull for test, the holes being closed with hand-riveted metal patches. These plates were submitted to the Bureau of Standards for examination metallographically for evidences of corrosion.

Seven specimens with transverse and longitudinal fibres cut from these plates were tested according to the method prescribed in the "U.S. Navy Specifications for Aluminium Alloy Sheet." The average results obtained are summarised in Table III and are compared with the original design and manufacturer's specifications.

TABLE III.

PHYSICAL PROPERTIES ZMC-2 .0095 ALCLAD SHEET.

	Specification guaranteed by manufacturer.	Design specifications.	Bureau Standards Test—1931.
Ultimate Tensile Strength, lbs./in.^{2}	50,000	50,000	56,300
Yield Point, lbs./in.^{2}	27,000	28,000	37,400
Elongation in 2 inches, per cent. ...	13	12	17.4

The results of these tests justify confidence in the metal. In every respect its properties still exceed design specifications by a very comfortable margin. There is evidently no loss in ultimate tensile strength, and very little loss indicated in elongation. Random and unofficial tests of new metal made in 1928, prior to assembly, indicated a yield point as high as 42,700lbs./in.^{2} and an elongation of 18 per cent. in two inches. Certainly, with an average elongation of 17.4 per cent. there is no evidence of an attack from intercrystalline corrosion.

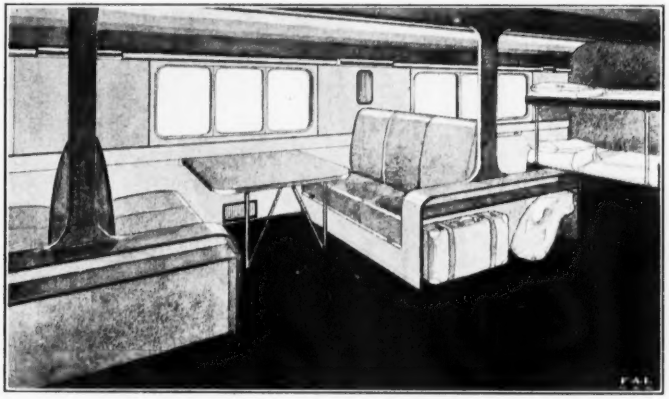

FIG. 9.

Interior of cabin showing collapsible table for dining purposes and method of converting seats into berths. Additional sleeping cabins immediately above lounge cabin in interior of ship.

Surface Corrosion

Of all the sheet specimens examined microscopically at 500 times magnification, none showed pits due to corrosion deeper than .0003in. In no case did the surface attack appear to have penetrated through the aluminium coating, which ranges from .0005 to .0007 inches in thickness.

Commenting on the examinations, Dr. L. B. Tuckerman[11] stated that the tensile tests and microscopic observations showed that corrosive attack had commenced on the aluminium protective coating, but was limited to that alone and should be regarded as in its very earliest stages and gives no cause for alarm. However, there was no evidence of penetration to the core of duralumin.

Coco Solo Tests Impressive

He directed attention to a series of tests conducted by the Bureau on 0.010in. alclad (practically the same thickness as in the ZMC-2 hull) exposed to outside weather conditions at Washington and at Coco Solo in the tropical Panama

Canal zone. Microscopic examinations of Coco Solo specimens after six, nine, and twelve months' exposure revealed that the corrosive attack had penetrated the aluminium coating only in isolated instances, whereas such a condition was not observed on the Washington specimens until after one year of exposure. (It should be explained that the air at Coco Solo is often heavily laden with salt spray and salt mist.) Other specimens after one year's exposure to such extreme conditions had a rather heavy coating of precipitated salt, and yet examination revealed that the corrosive attack had barely penetrated through the aluminium coating, and then only in a few isolated regions.

Tensile tests on Washington and Coco Solo specimens showed no loss in ultimate tensile strength, but the elongation values ranged from 9.5 to 16.5 per cent., as compared to an average value of 18 per cent. on unexposed material.

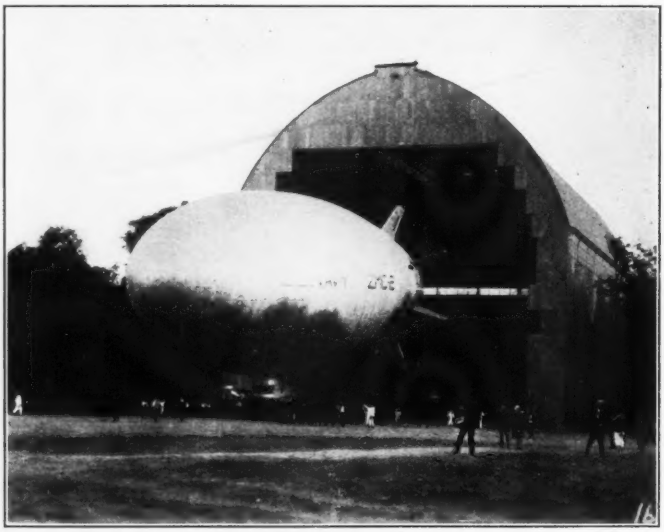

FIG. 10.

ZMC2 leaving its hangar August 19th, 1929, for her first trial flight.

With the experience available to date, the sponsors of the metalclad feel no hesitancy in predicting a life for a commercial ship of at least eight to ten years, in so far as corrosion of the hull is concerned. Certainly the Coco Solo salt exposure tests justify this estimate in consideration of the advantage of the greater resistance to corrosion of thicker sheets used for hull plating on large airships.

With respect to fatigue of the metal plating and seams from vibration and snap diaphragm action, it is pointed out that in the operation of the ZMC-2 no snap diaphragm action has been observed. In view of the ability of the plating to withstand vibration satisfactorily, as determined by laboratory tests, and the absence of such vibration under actual operating conditions, it is safely predicted that there need be no alarm from this cause.

The ZMC-2 has now been in operation for 21 months as a training ship, and no change in its structure has been found necessary, or desirable, except the

[11] Research Engineer, Bureau of Standards.

substitution of a balloon tyre landing wheel under the car in place of the oleo tube bumper. It has flown over 500 hours, and its operating record shows a diffusion of helium at the rate of about one-half that of fabric ships of similar size. Therefore, it is believed that in larger ships the diffusion would compare favourably with that of new goldbeater skin without any substantial increase with age, due to the absence in the metalclad of the wear and tear and more rapid deterioration which handicaps goldbeater skin.

Large Commercial Metalclads

With accumulated scientific data available, and utilising the experience gained from the design, construction and operation of the ZMC-2, a succession of larger airships has been investigated, the maximum size, so far, having an air displacement of 7,250,000 cubic feet (about 200,000 cubic metres), or 200 long tons gross lift.

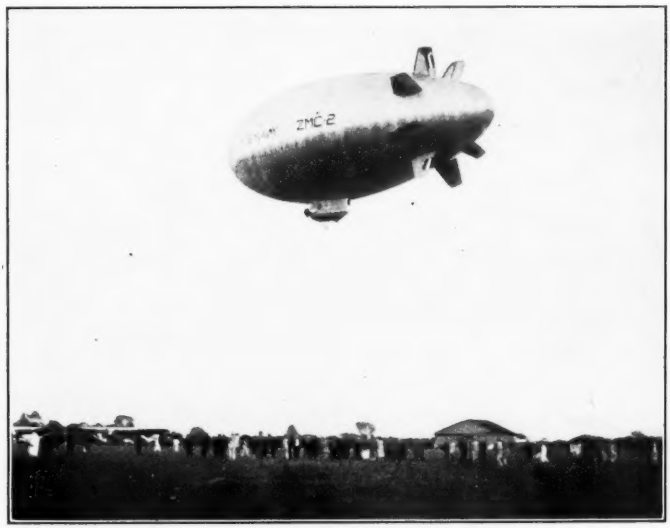

Fig. 11.

Economic investigations lead to the conclusion that, as airships gradually establish themselves commercially, the demand for higher speeds in excess of 100 miles per hour cannot be ignored.

Metalclad airships are eminently suited to fulfil this demand for ever-increasing speeds.

Due to the pressure principle used in metalclads, and to their structural unity of hull plating and framing, they will be able to provide safety and dependability at high speeds which other types of airships, at the present time, cannot hope to attain.

A thorough engineering investigation has not revealed any obstacles that might be in the way of construction of these large metalclads.

Future large merchant metalclads will have fineness ratios of probably 4.5 to 5. The hull shape, circular in transverse section, always will be an exact mathematical curve, to facilitate fabrication of hull plating and of internal structure. Such curves have been developed by our engineering staff; they have

very high prismatic coefficients at extremely low drags. At the same time they are simple mathematical equations.

In the bow of the ship will be located the mooring cone and a bridge with machinery for mooring masts, just as in other rigid airships.

Passengers' Accommodation Outside

A thorough study and comparisons have convinced us that the best day-time location of passengers for their comfort is in an outside streamlined car, suspended close to the hull, with passenger sleeping cabins and crew's quarters, and storage space located inside the hull. In the daytime they can enjoy the advantages of a glass deck and lounge in the outside car, with a visibility unsurpassed by any other vehicle of transportation.

FIG. 12.

Landing after first cross country trial flight.

In a helium-filled airship, inside sleeping quarters for passengers are actually the safest place in the ship.

The passengers' accommodation will be thoroughly ventilated, and, in short, it will incorporate the latest in point of comfort as much as weight considerations will allow.

The control room, with all its accessories of radio and navigation, and commander's bridge, will be in the bow of the car.

The propulsion machinery of a large and fast metalclad calls for careful attention, due to its size. Everything duly considered, it seems that the best location for present types of engines is on the outside, in nacelles suspended from the hull.

Engines Externally Disposed

Unless the inside arrangement of engines on the U.S. Navy airship now building proves to be much superior to nacelles, the latter method has decided advantages in simplicity of propulsion mechanisms, ready accessibility for repair

or changing engines while in the dock, and can be designed as roomy as an inside installation at the expense of slightly increased drag.

The best all-round design, we believe, from weight, drag and servicing standpoint is a nacelle, elliptical longitudinally and circular in cross section, with an engine at each end; one a tractor and the other a pusher.

Propeller scoops will be built directly on the nacelle and on the duct connecting it with the hull.

Water recovery apparatus will be incorporated in the metal hull opposite the engine nacelles.

The stabilising and control surfaces of the ship will be of multiple type, metal covered, originally developed by the Aircraft Development Corporation, and so successfully used on the ZMC-2.

Naturally, landing lines will be provided on the hull, designed for mechanical docking. Two shock-absorbing points for ground contact will be located on the car and the bottom fin respectively. The bottom fin will carry a built-in control cabin for emergency and ground landing.

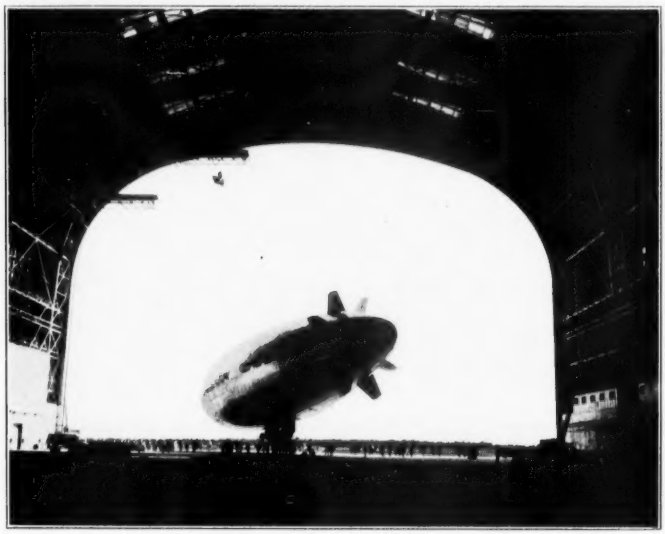

FIG. 13.

Landing at Lakehurst, New Jersey, September 12th, 1929, after 600 miles non-stop flight from Detroit

Metalclads Designed for Outside Docking

However, commercial metalclads will be designed to stay outside, in the weather, all the time while in service. They will either be on their way flying, or will be moored to a mast. Only in case of necessary overhaul, repair or lay-off will they be docked in a covered shed.

Returning to the hull, it will be built as a rigid streamline body resembling a monocoque system. On the outside it will have a smooth surface of double curvature. The only protrusions will be occasional small rivet heads. Inside will be the supporting structure of several large transverse frames, triangular in section, about eight feet (average) high, built of light, strong aluminium and steel alloy girders. These frames carry all the weights, dead and useful, of the

whole ship. They will be structurally rigid, without any radial wiring. To these frames will be attached passenger quarters, control car, power plants, fuel tanks, crew's sections, ballast, and mail and express compartments.

Longitudinally on the plating will run numerous light girders, connecting one big frame to the other. At intervals small unwired rings will break the length of longitudinals. There will be no other structure in the whole ship, except a secondary mount here and there for suspension of loads. No longitudinal keels or corridors will be in the hull, instead of which will be only an articulated passage on the bottom of the ship. All this structure will fit to the inside of the metal hull plating.

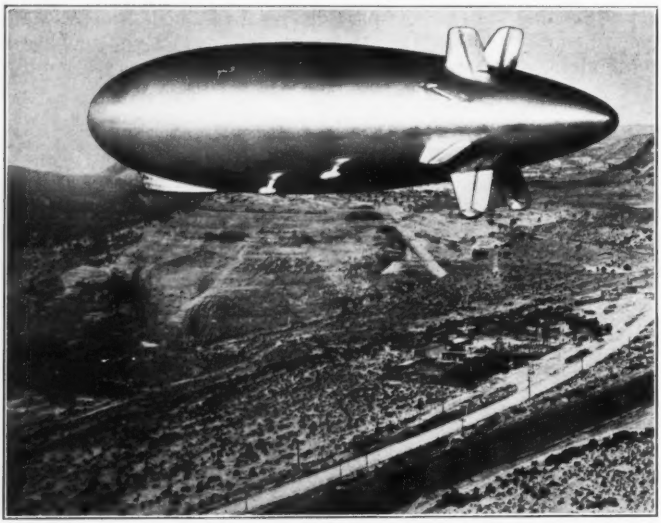

FIG. 14.

Large commercial metalclad, top speed 100 *m.p.h., as it would appear in flight.*

The whole hull, then, will be a single self-contained shell of metal, all parts rigidly joined, the framing supporting the hull plating and the plating in turn delivering rigidity to the entire hull. Nowhere will the designers resort to a maze of stress-carrying, undependable wires.

Sections Erected Vertically

The same method of vertical assembly in sections as used on the ZMC-2 will be followed on large metalclads. First, the hull plating will be cut on arc machines and sewed together by riveting machines. Next, the inside structure will be riveted to the skin, following its curvature. A certain length of hull finished, it will be turned into horizontal position and joined by another riveting machine to its adjacent section at one of the small unwired transverse rings.

The hull plating will not have the same thickness from bow to stern, but will vary in gauge in proportion to hoop tension in the skin. That is, it will be thinner at the bow and stern and progressively thicker towards the maximum section of the ship.

It is now possible to roll thicker sheets (about 0.15in. and up) in greater width (about 3ft. and up). This development will make possible wider hull panels than heretofore, which will mean less riveting. This advantage, inherent in large metalclads, means cheaper and faster construction and less gas diffusion because of diminished ratio of total length of seam to total surface area of the hull. That this method of graduation of skin thickness will save weight in large metalclads goes without mention.

The erection of the hull of large metalclads offers no new problems that have not already been solved. One of the most attractive features of metalclad construction is the fact that the erecting crew can walk with perfect safety directly on the inside of the hull plating when it is under slight pressure. This was done even on the ZMC-2, although the thickness of plating there was only .0095in.

The fact is then, that the crew of a metalclad airship in flight will be able to reach almost any location in the ship without special walkways, and will be able to stand on places around which the crew of a fabric-covered ship walks only with utmost caution.

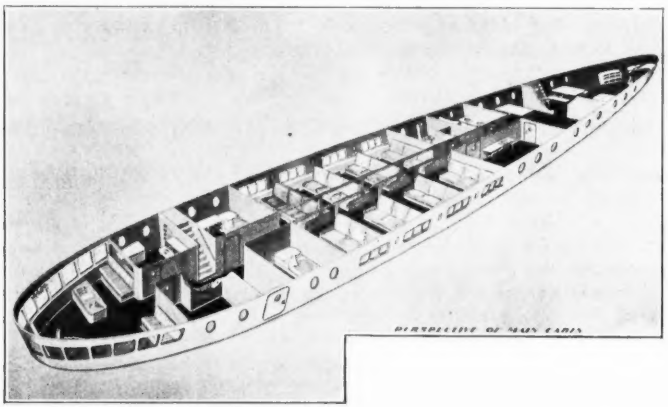

FIG. 15.

Large commercial metalclad, perspective of main cabin. Control room and officers' quarters forward. Passengers' lounge, culinary facilities and lavatories mid-section and aft.

Gas Chambers

The whole hull will be subdivided inside into gas chambers. The chambers will be made of gas-proof fabric, in reality patterned only as half gas cells, cemented at the equator of the ship to the hull plating and there also laced to the longitudinals. The upper half of the metal hull will comprise the respective gas chambers above the equator. Below the equator the several half-gas cells or fabric ballonets will complete the gas chambers.

Transversely the gas chambers will be separated by resilient diaphragms in the planes of the main frames, allowing for deflection of the diaphragm should a deflation occur, yet sufficiently rigid to restrain surging of the gas while in flight.

This type of gas chamber will afford minimum weight and take full advantage of gas-proofness of the metal plating of the hull. Besides it will make possible a complete deflation of the chamber, free of air, thus facilitating inflation with lifting gas without resorting to a more complicated procedure.

While the gas volume of the hull is subdivided for safety, there will be no partitions in the air space. The entire air space of the ship will serve as ballonet to compensate for gas volume changes. The air valves will discharge from, and the air supply will feed into, the ballonet air space.

Furthermore, this system of gas chambers, possible only in metalclad construction, will eliminate nearly all the dead air space and use it as part of the useful lift volume. The increase in lift gained this way amounts to about 4 per cent. compared to a conventional fabric-covered ship of equivalent air displacement. Applied to a 200 ton metalclad this feature would add over 12,000lbs. to the useful load.

It is contemplated to use only helium as a lifting gas in metalclads. Granted that compression-ignition engines will be available, the metalclad, lifted by non-inflammable gas, driven by safe fuel and constructed almost entirely of metal, will combine a degree of safety that has nowhere yet been attained in aircraft.

The gas and air valves will be located inside the hull, on top of the ship and in deep frames. Special hoods will be provided to carry the gas away, to allow easy access to the valves and also to protect them against weather. Deep ring frames will serve as passages to reach the top of the ship to facilitate inspection of valves, structure and cell fabric.

Three Pressure Supply Systems

The advantages of pressure in an airship are dealt with separately in the Appendix.

Summarising, three independent sources of air supply will be provided, viz., dynamic scoops, propeller scoops and power blowers.

The scoops will be built of metal, the opening gates balanced, the ducts aerodynamically streamlined; in short, a new conception of air scoop design will be introduced into airship engineering.

The dynamic scoops will be located in the bow of the ship to obtain the advantage of dynamic pressure in that area, again in the bow of the car and on the leading edges of the fins.

The propeller scoops, as already indicated, will be located at the engine nacelles.

The blower engines will be located inside the hull in two main frames.

All the mechanisms, scoops, blowers, and valves will operate automatically, being controlled by pressure regulators which have proved to be such a success in large electric power plants.

Control of Metalclad

In addition, manual controls will be installed for safety and for independent manœuvring at the pilot's bridge, where all the controls of the ship, engine, telegraphs, signal and indicating systems will be centralised. Here will be the veritable brain of the metalclad analogous to the bridge of an ocean liner and capable of equal methodical precision of operation. There is nothing acrobatic about flying an airship.

The metalclad hulls will be sufficiently rigid to sustain themselves in the air at reduced speed with only atmospheric pressure inside the hull. For this purpose air vents will be incorporated in the hull, ready to open and equalise inside pressure with atmospheric. However, at high speeds and in storms, also at landings and departures, when the aerodynamic and handling forces on the ship are severe, the pressure will prove of inestimable advantage and cannot but inspire confidence in the crew and a feeling of safety in the passengers.

The introduction of pressure into the hull raises the problem of communication between the hull and the control car. The pressure difference between

atmospheric in the car and inside pressure of the hull will be separated by airtight pressure doors.

Similar doors are not a novelty, but are being used in the mines, caissons, etc., with success. In a refined form they will be placed at points of exit from the hull, thus isolating at all times the hull pressure.

The bow mooring compartment will be separated by a pressure door at the bow entrance into the ship. In flight this compartment will be, however, under hull pressure. Entrances into the nacelles and the bottom fin will also be through pressure doors.

Fire Hazard Eliminated

One of the undeniable features of metalclads will be their fireproofness. Not only because of helium gas, but due to the all-metal construction, they will dispel the dreaded danger of fire on board an airship.

Should fire break out in the passengers' quarters or in one of the power plant nacelles, provision will be made to flood the section instantly with quenching helium gas, a perfect extinguishing medium.

Summary

There are numerous other superior advantages of the metalclad system of rigid airship construction. Let us sum up only those outstanding ones without going into further detail.

To those who for many years have been engaged in the study and development of the metalclad they appear as follows:—

Simplicity of design and construction.
No indeterminate hull stresses.
Fireproofness.
Durability of plating.
Superior gas tightness.
Ease of maintenance and inspection of hull.
Rigidity of hull shape at high speeds.
Greater gas volume for the same air displacement.
No moisture absorption.
No loss of speed due to flapping fabric.
Superiority at high speed.
No deterioration under tropical sun.
Ability to increase strength by higher pressure, yet rigid enough to fly with atmospheric pressure.
Wider range of inside pressure variation.
Perfect electric bonding of all structural parts.
Economy in operation.
Weatherproof qualities.
Commercial safety.
Adaptability to outside mooring at terminals.

Two of these advantages, however, are of paramount importance to commercial operation and distinguish the metalclad airship above all others. First, inherent safety, and second, ability to operate continuously at high speeds in the region of 100 miles or more per hour, both of which are due to its:—

(*a*) Improved principles of design.
(*b*) Choice of materials.
(*c*) Integrity of hull structure.
(*d*) Method of operation.

Comparative Weights of Metalclad and Fabric Airships

The remaining question is one of comparative weights. Most critics are

agreed that if the handicap of excessive weight of metal covering over fabric diminishes with increase in size, then their objections are overcome.

Tables IV. and V. offer comparisons of the respective weights of two fabric-covered airships with two metalclads of approximately equal size. These comparisons are not guaranteed as perfect.

The metalclads have not been built, hence their useful load is based on theory, although their dead weight estimates include a generous tolerance as well as provision for a structural safety factor of 4 under normal operating conditions.

Precise data of the fabric-covered ships are not available, but it is believed the figures used are sufficiently accurate to indicate the trend of comparative weights. In these tables it is assumed all ships are helium inflated.

TABLE IV.

R.100 British Airship VS. MC-50 Metalclad.

Item.	Comparative Data. R.100.*	MC-50.
Displacement (Air), ft.^{3}	5,600,000	5,000,000
100% Gas Volume, ft.^{3}	5,000,000	4,900,000
Total Lift, Helium Lifting .062 lb./ft.^{3}, 95% full, lb.	294,000	289,000
Weight Empty, lb.	189,000	174,000
Useful Load, lb.	105,000	115,000
Useful Load/Total Lift	35.8	39.8
Useful Load per 1,000ft.^{3} Displacement, lb. ...	18.8	23.0
Motors	Rolls-Royce Condor (6)	Rolls-Royce " H " (4)
Horse-Power	3,960	3,300
Maximum Speed, m.p.h.	82	81
Useful Load per Horse-Power, lb.	26.5	34.9
Number of Gas Cells	15	9
Lift of Largest Cell, 95% full, lb.	32,400	41,000
Lift of Largest Cell/Useful Load	31.8	35.7
Lift of Largest Cell/Total Lift	11.0	14.2

Time will not permit a detailed analysis of all the different features of two totally different airships that contribute to the difficulty of accurate comparison. However, certain considerations should be pointed out. In the first place, in the R.100 passenger accommodations are internally disposed, and in the MC-50 they are provided for in a car attached underneath the hull. One method subtracts from the gas volume, thus decreasing total lift, while the other adds to the drag, thus increasing energy requirements. This accounts partially for the fact that the R.100 has 600,000 cubic feet of non-usable volume which is not available for lifting gas, whereas the metalclad loses only 100,000 cubic feet. Dissimilarity in structural arrangement, plus the absence of an intervening layer of dead air between the helium and the outer cover of the MC-50 also account largely for this difference in loss of gas volume.

Due to gas chamber arrangement, the practical absence of unused dead air space above and below the equator is a distinct feature of the metalclad design.

In the metalclad design one obtains approximately the same gas volume as the R.100, with 11 per cent. less air displacement, resulting in less hull drag and requiring less engine power for a given speed.

* R.100: The weight empty of the R.100 has been taken as 86 tons, in accordance with Mr. Wallis' statement in his lecture before the Royal Aeronautical Society, May 10th, 1928 (see " Aircraft Engineering," January, 1930, page 10). In the absence of any definite information the ton has been considered as metric (2,200 lbs.).

In the R.100 six Rolls-Royce Condors are used, and in the MC-50 four Rolls-Royce " H " type engines are used. If the R.100 were equipped with the latter and newer type engine no doubt some weight would be saved, but this is offset by the absence of a water-recovery system not included in the R.100 design but which is essential to operation with helium. The MC-50 weight estimates include a water-recovery system.

With respect to both hull plating and structure, the MC-50 is designed for 100 m.p.h. maximum speed. In reducing its speed to approximately that of the R.100 (81 m.p.h.) the weight of the extra power plants only has been subtracted, and no allowance has been made for a possible structural weight saving due to this reduction in speed. In spite of this penalty the metalclad exceeds the R.100 in useful load by 10,000lbs. The ratio of its useful lift to total lift is 39.8 per cent., compared to 35.8 per cent. in the R.100. Measured in pounds of useful load per 1,000ft.^{3} displacement, the metalclad again shows to advantage, carrying 23.0lbs. versus 18.8lbs. in the R.100.

The useful load per horse power in the metalclad is 34.9lbs., as compared to 26.5lbs. in the R.100. This wide difference is partially explained by the fact that the metalclad requires less air volume to obtain approximately the same gross lift, resulting in smaller hull dimensions, less drag, and consequently less power plant installation. The smooth circular contour in contrast to the concave polygonal shape of the R.100 also induces less drag.

However, attention should be directed to the weight penalty imposed on the R.100 by reason of its having 15 gas compartments, whereas the metalclad has only nine. If this weight of additional fabric and transverse frames were eliminated it is believed the R.100 would more nearly approach the MC-50 in performance.

It should be emphasized that this comparison is undertaken with no thought of criticism, nor with the idea of pleading the cause of the metalclad. Its purpose is to eliminate the mental hazard with which one most always is confronted when the idea of covering an airship with metal is suggested. Evidently the handicap of excess weight is more apparent than real.

The metalclad, as it increases in size, again overcomes the excess weight handicap when compared with a Zeppelin of equal displacement, as is indicated in the following table.

TABLE V.

ZRS-4 ZEPPELIN VS. MC-72 METALCLAD.

Item.	Comparative Data. ZRS-4.*	MC-72.
Displacement (Air), ft.^{3}	7,250,000	7,250,000
100% Gas Volume, ft.^{3}	6,850,000	7,080,000
Total Lift, Helium Lifting .062 lb./ft.^{3}, 95% full, lb.	403,000	417,000
Weight Empty, lb.	233,000	249,000
Useful Load, lb.	170,000	168,000
Useful Load/Total Lift	42.2	40.3
Useful Load per 1,000ft.^{3} Displacement, lb. ...	23.5	23.2
Motors	Maybach (8)	Maybach (8)
Horse-Power	4,480	4,480
Maximum Speed, m.p.h.	84	84
Useful Load per Horse-Power, lb.	38.0	37.5
Number of Gas Cells	12	11
Lift of Largest Cell, 95% full, lb.	57,000	49,000
Lift of Largest Cell/Useful Load	33.5	29.1
Lift of Largest Cell/Total Lift	14.1	11.7

* ZRS-4: The data for this ship based on recent unofficial estimated figures.

The ZRS-4 Zeppelin, described in Table V, now being built for the U.S. Navy, is designed as a military ship. Therefore, in preparing a weight estimate of a metalclad (MC-72) of equal air displacement, accommodations are provided for the crew and assumed military equipment only. Likewise the power units are identical in type and in number. In the Zeppelin the engines are internally disposed, and in the metalclad they are externally mounted in tandem. The additional drag of the power cars in the metalclad is compensated for by less drag of hull—due to smaller fineness ratio, smooth circular shape of hull and to the absence of loss of energy through transmission.

The more efficient use of air volume in the metalclad is again repeated, the dead air loss being only 170,000ft.^{3}, as compared to approximately 400,000ft.^{3} in the Zeppelin. The design of the metalclad is based on a structural safety factor of 4 under normal operating conditions, compared to 2.5 in the Zeppelin. In spite of the structural weight penalty thus imposed, the useful load of the metalclad is only 2,000lbs. less than the Zeppelin. The ratio of useful lift to total lift in the Zeppelin is 42.2 per cent., and in the metalclad 40.3 per cent. Measured in pounds of useful load per 1,000ft.^{3} displacement, the metalclad with 23.2lbs. very nearly equals the Zeppelin with 23.5lbs. Also in useful load per horse power the two ships show almost equal performance, the metalclad carrying 37.5lbs. and the Zeppelin 38.0lbs.

In both tables it is believed the weight estimates of the two metalclads are reasonably reliable. They are based on careful engineering investigation and include liberal allowance for variation in detail. The comparisons and preceding analyses indicate and seem to justify two conclusions:—

1. As the metalclad airship increases in size the excess weight handicap progressively decreases and finally disappears, resulting in a performance equivalent to that of the conventional fabric-covered airship.

2. As the super metalclad airship increases in speed its performance exceeds that of the conventional fabric-covered airship, having an equal structural safety factor.

It is hoped that no one will misinterpret any technical comparison or personal conclusion as a reflection on the valuable contribution the designers, builders and operators of fabric-covered airships have made to lighter-than-air development. Airship development is too young to permit of intolerance and unalterable opinions.

Comparison has been resorted to in order to clarify description and with the honourable hope that it might stimulate engineering inquiry into the art as a whole. Airships have demonstrated they can fly, even around the world. But this is not enough. If they are to be adapted to commercial use the whole question of design and construction must now be reviewed from this point of view.

Commercial Application

In spite of contrary predictions from professional and other sources it has been actually demonstrated that a metalclad airship can be built; that it will hold helium and that it will fly. One cannot dispute a fact.

Numerous advantages are claimed for its superiority in the larger sizes where the excess weight handicap of metal over fabric disappears. As to certain advantages all will agree and as to others opinion may differ.

But granting all the merit claimed for the metalclad as a progressive step forward, what is its application or that of any other airship? What can it be used for? How will it perform commercially?

Let us examine a metalclad of approximately 200 tons gross lift engaged in trans-Atlantic transport over two routes—London to Montreal and London to Washington. The general characteristics of such a ship equipped with oil burning engines appear in Table VI.

London—Montreal

The distance from London to Montreal is 3,240 statute miles. A 200-ton metalclad cruising at 75 m.p.h. in still air would require about 43 hours for the voyage. In actual practice adequate allowance should be made for prevailing adverse winds when westbound, plus occasional delays on account of detours around storm centres. An allowance of lesser degree should also be made for eastbound voyages. A reasonable expectation would be 60 hours between terminals westbound and 50 hours eastbound.

In addition to carrying 50 per cent. fuel reserve, such a ship could transport 50 passengers plus 18 tons of mail and express westbound and the same number of passengers plus 25 tons of mail and express eastbound. The better performance eastbound is due to more favourable winds prevailing in that direction.

London—Washington

The distance from London to Washington is 3,680 statute miles. A 200-ton metalclad airship travelling this distance in still air would require about 49 hours for the voyage. Making the same allowance as previously for prevailing adverse head winds westbound and occasional detours around storm centres in both directions would justify the reasonable expectation of 70 hours for the westbound voyage and 60 hours for the eastbound voyage.

In addition to carrying 50 per cent. fuel reserve, such a ship could transport 50 passengers plus 12 tons of mail and express westbound, and the same number of passengers plus 18 tons of mail and express eastbound.

TABLE VI.

200-TON COMMERCIAL METALCLAD AIRSHIP FOR TRANS-ATLANTIC SERVICE. GENERAL CHARACTERISTICS.

Length Overall	718.0ft.
Maximum Diameter	141.7ft.
Height Overall	151.0ft.
Fineness Ratio	5
Displacement (Air)	7,260,000ft.^{3}
Gas Volume	7,080,000ft.^{3}
Gas Compartments	11
Total Horse-Power	5,000
Gross Lift at 95% full of Helium, Lifting .062 lb./ft.^{3}	417,000lb.
Weight Empty	*258,000lb.
Useful Load	159,000lb.
Maximum Speed	87 m.p.h.
Effective Cruising Speed	75 m.p.h.
Passenger Accommodations	50
Mail and Express Load	12 to 25 tons (varying with range)

* Based on assumed availability of oil-burning engines.

The capital investment required for initiating such a service with three airships over either route it is estimated would be approximately as follows:—

TABLE VII.

ESTIMATED CAPITAL REQUIRED—TRANS-ATLANTIC ROUTE.

	$
Three metalclad airships (200 tons each)	15,000,000
*25,000,000 cu. ft. helium at $40 per M., including freight	1,000,000
Spare parts, reserve engines, etc.	450,000
Two airship hangars (225,000 sq. ft. each) at $10 per square foot	4,500,000
Five mooring masts and facilities	1,000,000
Helium purification plant and gasometers	750,000
Repair shops	200,000
Crews' quarters, miscellaneous buildings	200,000
Terminal buildings and equipment	300,000
Land	200,000
Electrical equipment, radio, etc.	400,000
Unforeseen items	1,000,000
Working capital	5,000,000
Total Capital Investment required	$30,000,000

* Helium costs from $12 to $30 per 1,000ft.³, F.O.B. Refinery depending on quantity.

The above figures are not guaranteed as correct, but are the result of a careful analysis based on the best information available. Likewise the following estimates of operating costs, in Table VIII, necessarily involve certain assumptions inasmuch as no authentic experience is available at this time on which to base exact figures. It is believed no important or essential items have been overlooked, and while future experience may disclose that the individual figures are somewhat in error, still it is believed they are reasonably certain for the purposes intended.

TABLE VIII.

OPERATING COST PER MILE.

200-Ton Metalclad Airship engaged in Trans-Atlantic Service. Sleeping Accommodations for 50 Passengers; Cruising Speed, 75 m.p.h.; Effective Fuel Reserve, 50%; Cost Based on Operating 250,000 Miles per Annum.

Item.		Cost per Mile. $
1. Executive		0.30
2. Administration		0.45
3. Traffic		0.45
4. Transportation:		
(*a*) Fuel	0.16	
(*b*) Crew	0.87	
(*c*) Helium	1.48	
(*d*) Miscellaneous	0.40	
		2.91
5. Terminals		1.00
6. Maintenance		1.98
7. Communications		0.45
8. Insurance		3.00
9. Depreciation:		
(*a*) Engines	1.16	
(*b*) Airship	2.50	
(*c*) Buildings	0.80	
		4.46
10. Unforeseen items (20%)		3.00
Total Estimated Cost per Mile ...		$18.00

Perhaps the most interesting item under operating charges is the small expense of helium, only eight per cent. of the total operating cost per mile. This figure assumes that 100 per cent. of the volume of a ship will be wasted during the year through diffusion, valving, operating losses, occasional superheat, etc. Actually, such a large wastage is contrary to experience. Also, the cost of this helium is increased to include expense of repurification and storage.

It is believed the estimate includes an excessive charge for helium, and therefore it may be assumed to represent the maximum average.

Sources of Income

Although the above estimated operating cost is based on an annual operation of 250,000 miles, let us assume that only 80 per cent. of the scheduled trips, or 200,000 miles, will be flown, and that 20 per cent., or 50,000 miles, will be cancelled. This deduction is made to allow for delays on account of extremely unfavourable weather and for unforeseen repairs and necessary overhaul. This would average for the two alternative routes 58 one-way trips completed by each ship per annum

It is assumed, of course, that an air mail subvention will be supplied by the Government. Ample precedent exists for this, for history discloses that all new forms of transportation have looked to governmental aid at their original inception. This has always been true of the merchant marine; it was certainly true of the early railroads; it is still true of the automobile, the highways all being constructed at public expense; consequently in suggesting the advisability of a subvention or subsidy for airships one is only repeating history. To ignore the necessity for this would open one to criticism for failure to face the facts.

The air mail subvention ($12 per mile) contained in Table X is arbitrarily selected and is based on a maximum mail load of 10,000lbs. per trip. Possibly a higher rate per mile might be justified during the pioneering period and until traffic from other sources justifies a reduction.

Experience discloses that ordinary first-class mail runs about 40 letters to the pound, and consequently for this amount of money 400,000 letters could be transported at a cost of 11c. per letter. It is believed that the general public will gladly pay this increased postage because of the time saved, with the net result that as the traffic increases the mail service will be placed on a self-sustaining basis requiring not a dollar of outlay from the public treasury. For example, no one hesitates to put a special delivery stamp costing 10c. on a domestic letter in order to expedite its delivery by only a few hours at its point of destination. Certainly if a ten cent. stamp attached to a foreign letter will expedite its reply by a week or ten days, most everyone will want to use it.

Volume of Mail and Express

First class mail between the United States and Europe averages 35 tons per week each way. Of this volume 30 per cent., or over ten tons, goes to Great Britain; 15 per cent. to France, and 10 per cent. to Germany. Three airships, each operating on a schedule of one round trip every ten days, would need only 24 per cent. of this volume to carry their contract load requirement of 10,000lbs. first class mail per trip. Improved service and speed would increase the volume.

In addition there is the Canadian mail, which averages about 17 per cent. of the outgoing U.S.A. first class mail. What proportion of this is trans-Atlantic is not known, but its volume is relatively large.

According to estimates recently published[12] the volume of merchandise suitable for trans-Atlantic air express is enormous. Table IX gives the details.

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[12] J. S. McDonnel, Jr., in "Airway Age," February, 1931, based on analysis for 1925 by Dr. Carl Pirath.

TABLE IX.

TRANS-ATLANTIC EXPRESS.

Estimated Annual Volume Between U.S. and Europe Suitable for Air Transport.

Precious Merchandise	4,600 tons
Express Packages	14,300 ,,
Parcel Post and Prints	14,600 ,,
Total	33,500 tons

This volume is exclusive of first class mail, and no doubt increases in direct proportion as foreign trade expands. Three airships operating over the North Atlantic route could carry on an average only 5 per cent. of this volume. Unquestionably an ample amount of express is of sufficient value to pay the higher rate suggested, $1.75 per pound, to fill these airships and several other merchant fleets to cargo capacity.

Passenger Traffic

It is not unlikely that the merchant airship will repeat the history of the commercial airplane, relying on its importance as a mail and express carrier rather than as a passenger transport during its early stages. Once its reliability and safety have been demonstrated, passenger patronage will follow naturally and receive greater emphasis. That there is ample volume of traffic of this nature is disclosed in a study recently completed by Dr. Jerome C. Hunsaker[13], formerly Commander, U.S. Navy.

According to his analysis 500,000 passengers per annum travel each way between the United States and Europe. This does not include passengers using Canadian ports. 100,000 of these travel first class; 50,000 pay extra fare for better accommodations; and 25,000 pay over $500 for a one-way trip.

Assuming that each airship would complete 80 per cent. of its scheduled trips, and on each voyage 75 per cent. of its accommodations were sold, this would indicate a total patronage of 2,204 passengers per annum per ship. On this basis three airships would carry about 6,600 passengers per annum, or less than one per cent. of the total volume of all classes, and about three per cent. of first class passengers.

The fare of $900 is arrived at on the basis that, via airship, four days are saved to the business executive, plus the fact that his commercial transactions are expedited, thus justifying the difference between the price he pays for de luxe accommodations on an ocean liner and the higher fare on a merchant airship.

That there is a demand for greater speed for which the public will pay the price is evidenced by the recent success of the "Europa," holder of the speed record for trans-Atlantic crossing. In her first year of service it is reported this ship carried about 500 passengers per trip in excess of the average of any other liner engaged in Atlantic service.

In not many years trans-Atlantic merchant airships will be competing with ocean liners for first-class passengers on the basis of both speed and comfort, with daily sailings from all principal ports. Frequency of service will increase volume and stimulate the "riding habit" with the prospect that there will be enough profitable business to go around for all who have the vision and courage to engage in the venture. Their use will not be limited to the North Atlantic alone. It is no idle prophecy to visualise airship lines encircling the globe,

[13] Hon.F.R.Ae.S., formerly Naval Attaché, American Embassy in London; Vice-President Goodyear-Zeppelin Corporation.

supplementing present land and water transport facilities and penetrating remote regions of the world now little known to civilised man.

As is always true when any new mode of transportation is contemplated, the question inevitably arises, "Will it pay?" Otherwise it cannot be defined as a commercial undertaking. Can the merchant airship sustain itself financially as well as statically?

It is maintained that ample evidence has been submitted to prove that an extraordinarily large volume of high-class traffic already exists on the North Atlantic route. Also, that only a small percentage of this volume is necessary to furnish employment for a fleet of airships. But on what terms of employment will the balance sheet reflect black ink operations? Table X, which compares the estimated annual income and annual operating expenses, undertakes to throw some light on this important question.

Assuming that three airships are operated on the route, this volume of traffic would indicate an annual profit of $6,265,800, or approximately 20 per cent. net (excluding taxes) on a total investment of $30,000,000 .

It is not unwise to suggest that any company undertaking the development of such a service should by special governmental action be exempt from all taxation for at least five years on account of the pioneering hazard involved.

TABLE X.

ESTIMATED ANNUAL INCOME FOR ONE TRANS-ATLANTIC 200-TON AIRSHIP.

(Assuming 75% pay load capacity being utilised and 80% of scheduled trips—200,000 miles—being completed.)

		$
Mail (10,000lb. per trip):		
200,000 miles at $12 (subvention)		2,400,000
Express (20,000lb. per trip—58 trips):		
1,160,000lb. at $1.75		2,030,000
Passengers (38 passengers per trip—58 trips):		
2,204 passengers at $900		1,983,600
Total Operating Revenue		$6,413,600
OPERATING COST:		
Annual cost on basis of 100% schedule 250,000 miles at $18	$4,500,000	
Deduct saving on account of cancellation of 20% of scheduled trips (50,000 miles), 50,000 miles at $3.50* ...	175,000	
		4,325,000
Annual Profit per Airship		$2,088,600

* Estimated value of contingent operating charges.

This was considered wise policy with respect to the early trans-continental railroads in the United States and has been applied in other instances.

Twenty per cent. profit may sound reasonable to the conservative mind, but less attractive to the more speculative individual who might be induced to embark on such an enterprise. However, one cannot solicit Government aid in the form of a subvention or a subsidy during the pioneering stage and expect to harvest exorbitant profits. Once the demonstration period is over and the art of construction and operation becomes well established, the question of adequate profits will take care of itself. The world never turns its back on progress, nor has it ever been known to refuse a faster means of transport.

But there is an additional profit, a by-product, quasi public in scope, fundamental in nature, that cannot be ignored. It is not subject to exact measurement in dollars or in pounds, but it is just as real nevertheless. Men experienced in trade would call it improved "accessibility."

Other things being equal, as between two markets, accessibility decides the issue for the customer. No store, no business, no world state can prosper if it lacks accessibility. The most fertile soil on earth remains barren and the richest diamond mine possesses no intrinsic value if accessibility is denied.

And let it be remembered that as civilisation advances and transportation improves, accessibility is determined not by the tape line but by the hour glass.

The greater the distance between trade centres, the more the value of speed is amplified.

Because of its superior range over great distances, it is here that the airship finds unusual opportunity for service. It is destined to play the rôle of major importance in the general advancement and prosperity of mankind. Its future is as brilliant as that of the first steamship. As a means of promoting the peaceful pursuits of commerce, as an instrument for bridging, quickly, physical or artificial barriers that often are obstacles to better understanding among nations, it is an international asset. Because of its speed, the airship will expedite trade and thus increase the volume of commerce. Its general application to world trade routes is inevitable.

Indeed the airship is destined to revitalise the arteries of international trade. The world state that refuses it employment will not unlikely awaken some morning suffering from "hardening of the arteries." And this disease is defined by physicians as the product of habit, not of inheritance.

It is not sufficient that one's past is secure or that one's present is promising. The big responsibility facing mature men everywhere is to neglect no opportunity that will make the future more secure, for the generation to follow. If not, what other philosophy justifies one's existence?

Foreign Trade

England perhaps has more to gain from the merchant airship than any other country. Ready accessibility to the far-flung Dominions and possessions of the Empire is of prime importance. It has been said that one out of every four citizens of the United Kingdom is dependent upon foreign trade for a living. If this be true, then no price for speed is too dear to pay that will make more secure England's already major position in world commerce.

The actual figures of the Empire's trade offer supporting evidence. According to reliable statistics, for the five year period ending with 1929, the world's foreign trade, including both imports and exports, averaged almost 66 billion dollars or 13½ billion pounds sterling per annum. The British Empire's share of this trade averaged almost 21 billion dollars or over 4 billion pounds per annum.

Over 31 per cent. of the world's trade virtually dominated by one group of English speaking people. No wonder Britain is interested in foreign trade. It is her life's blood. Its volume is the reward to her people for having carried the torch of civilisation to the farthest ends of the earth.

One finds their counterpart in the Pilgrims, Quakers, Puritans, Cavaliers, Scotch and Irish, who with other nationalities, transformed the United States from a wilderness into a world power. In the United States foreign trade for the same period averaged 9 billion dollars, or almost 2 billion pounds per annum, representing about 14 per cent. of the world's total. There, it is estimated, one out of every ten citizens is dependent upon world trade for a living.

According to Lloyd's Register, the world's gross tonnage of shipping averaged 66 million tons for the five year period ending 1929. Of these vessels

22½ million tons or 34 per cent. flew the British flag, and 15 million tons, or almost 23 per cent. flew the American flag.

Combined, these two great English speaking groups conducted 45 per cent. in value of the world's foreign trade and furnished bottoms for 57 per cent. of its tonnage. Certainly their common economic interest in its advancement varies only in degree, and not in purpose.

This enormous volume of trade illustrates how dependent modern existence is upon adequate transportation. There was a time when life consisted of three bare necessities—food, shelter and raiment. But to these another has been added —transportation—which might be termed the " fourth dimension " of life. In its perfection man has spared no effort, and from its application man has gained untold benefits. In fact, some historians classify transportation with the alphabet and the printing press as the three greatest aids to the march of civilisation.

Evidently it is a fundamental enterprise in which the adventurer in aeronautics is engaged, whether it be heavier-than-air or lighter-than-air. Progress may seem slow at times, but universal application is its certain ultimate goal.

It is in foreign trade that the airship particularly finds its greatest usefulness. To repeat, its primary function is to promote accessibility of world markets. In so doing it will shorten the line of communication between the buyer and seller and enhance the prosperity of both.

It should be recalled that at the present time foreign commerce moves at freight train speed. The average ocean vessel travels about 20 miles an hour. This is a fair estimate of the movement of a freight train averaged over a 24-hour period. Consequently, foreign communications, in so far as personal contacts are concerned, transport of samples, spare parts and repairs and transmission of documentary evidence of contracts, of bank transfers and of highly-important mail are all being conducted at freight train speed. The process is slow and retards trade.

If it is important to speed up communications via airplane, faster train schedules, etc., in the conduct of domestic business, it is certainly of equal importance in foreign trade. Anything that facilitates access of the consumer to the source of supply has a profound influence on steering the direction that trade will take. Therefore it is inevitable that merchant airships applied internationally will have a profound influence in steering a greater volume of commerce to the doorsteps of world states that give it employment.

There are two methods of merchandising:—

(1) Price, quality, service.

(2) Quality, service, price.

Experience discloses that in the long run the latter method—quality first, service second, and price last—is the better and more enduring. It produces satisfied customers who send repeat orders. But this method requires personal contact. It is not a mail order business. Educational effort and patient demonstration are needed, and, equally important, the sales representative must have an intimate knowledge of the needs, tastes and desires of his customer, which he can acquire only through personal contact. How particularly true is this of foreign trade, where language, habits and climatic influence all differ so greatly.

So here again we find economic usefulness for the merchant airship. It offers a new form of international transportation that will enable a business representative to cover twice or three times the territory, establish more personal contacts, develop more business, and thus increase the prosperity of both his enterprise and his country.

It is apparent to the most casual observer that if happiness and prosperity are to supplant growing unrest and distress in world states, then it is essential above all things that the products of labour find ready distribution. This is fundamental, for where there is a sale there is need for production, and if there is production there is employment for both capital and labour, and if there is employment, both happiness and prosperity prevail.

Certainly no world state, whose domestic market is deficient and whose foreign market is feeling the challenge of growing competition, can ignore this new agent of distribution—the airship.

England established her supremacy as a maritime nation by beginning immediately after the end of the Napoleonic Wars. The World War has ended and the age of air commerce is at hand. Who will establish supremacy this time?

Well, it is hoped all will agree that during this distressing period of re-adjustment, supremacy will be sought in terms of quality of service rather than in volume of profits. There is room enough for all of us in this world. It is full of natural resources. We have not begun to develop its unlimited possibilities. If we only will have sense enough to release ourselves from the provincial shackles of the past and make use of the tools modern science affords, the seeds of prosperity and peace will find root in fertile soil.

International Co-operation

The airship cannot be operated in foreign service without international co-operation. This is perhaps its most fascinating feature. In the first place, navigating an airship is primarily a problem in applied meteorology. This means collecting a world-wide system of weather reports eventually giving a twice-daily picture of meteorological conditions over the seven seas. No one nation can do this. All must help on a reciprocal basis. As a result of conferences held in London and Paris in 1928, and in Copenhagen in 1929, and attended by representatives of the principal maritime nations, this programme has already been launched. The data, collected by radio, is now being used to aid ocean shipping and to verify domestic forecasts. With proper international co-ordination, the expansion of this weather service will find a usefulness of unlimited possibilities.

The question of ports comes in for consideration. An airship must have access to a safe harbour equipped with a mooring mast and other facilities, just like an ocean liner must have access to adequate docking facilities in a foreign country. Just as all harbours are open to all ocean vessels through treaty arrangement, in similar fashion airship terminals must be made available, or else foreign operators must be licensed to build their own. This means standard couplings, fittings, uniform mooring methods, and many other features that call for international co-operation. Without this there can be no foreign trade.

Helium

While it is highly improbable that helium in paying quantity is limited to any one part of the world, still the fact remains that, so far as actual commercial production is concerned, the United States at present enjoys a monopoly. There is no law against its export. The power to license export of helium for specific purposes is vested in the President and certain members of the Cabinet.

Immediately following the disaster to the R.101, high ranking officials announced that the United States Government would look with favour on applications from foreign governments seeking export helium for use in the development and operation of commercial airships. There is an ample supply for this purpose, as is evidenced by the following survey made in 1928:—

TABLE XI.

ESTIMATED VISIBLE HELIUM SUPPLY IN THE UNITED STATES.*

Kansas	2,000,000,000	cu. ft.
Texas	3,000,000,000	,,
Colorado	2,000,000,000	,,
Other States	3,000,000,000	,,
Total	10,000,000,000	,,

* Survey made by Helium Company of America, Louisville, Ky.

More recent investigations serve to increase this volume, perhaps to double this amount. At least it is not an exaggeration to say that the present visible supply in the United States is sufficient for 1,000 and perhaps 2,000 super airships, and it is logical to assume that, when demand justifies the cost of exploration, new sources of supply will be found in other parts of the world.[14]

Recently Dr. Hugo Eckener, representing the Zeppelin Luftschiffbau, of Germany, it is reported, has been granted a licence to obtain sufficient helium to inflate the new 7,000,000ft.[3] commercial Zeppelin now being built at Friederichshaffen for trans-Atlantic service. Unquestionably, this same international co-operation would be extended to the United Kingdom should its commercial airship policy be amended to specify the use of helium.

Reciprocal Airship Mail Contracts

Last year a measure was introduced in Congress known as the Merchant Airship Bill. Hearings on the bill had not been completed when Congress adjourned, March 4th. Included in the bill are certain sections of existing Admiralty Law which are likewise applicable to airships, notably fixing limited liability on the carrier, insurance regulations, and other important features.

The purpose of the bill is to encourage construction in the United States by American capital of American airships for regular operation on foreign trade routes by American operators. These airships are to be eligible for foreign mail contracts in accordance with the principles long established by Congress for the encouragement and protection of the American Merchant Marine. Airships eligible for mail contracts must be capable of carrying not less than 10,000lbs. of mail and a suitable commercial load over distances in excess of 2,000 miles. Payment for the transportation of mails is provided for on a mileage basis, varying with contract load and route distance, the maximum being fixed at $20.00 per mile.

Now, obviously, it is uneconomical to transport mail in one direction only. So when the bill is reintroduced at the next session of Congress, in December, it is hoped it may be amended to include authority for negotiating treaties with other world states whereby reciprocal airship mail contracts may be arranged to the mutual benefit of both parties.

Here is a form of international co-operation of a most practical nature. It is already being applied to ocean shipping, but on a basis of compensation not liberal enough for airships. European ocean vessels now carry American mail eastbound, and American liners carry European mail westbound.

International Operating Company

Assuming that such an amendment to the Merchant Airship Bill might be received with favour, and that suitable treaty arrangements with other world states would follow, it is conceivable that the plan might function best through an International Operating Company. In this event one-half of the airships

[14] Recent announcements of discoveries of helium in the Mackenzie River Valley, Canada, and in the Belgian Congo, confirm this prediction.

necessary for frequent service would be constructed in each of the two countries that are high contracting parties to the treaty. Each ship would fly its own flag and be manned by a crew of its own nationality. The ships would be leased to an International Operating Company, ownership of which would in turn be equally divided between the two respective national groups initiating the enterprise.

Can anyone advance a logical reason why this should not be done? What is to become of all this promise about commercial air transport paving the way for a better international understanding, unless airmen are willing to take the initiative in bringing about its realisation?

If it is worth while to bridge a river in order to connect two cities, how much more important it is to bridge an ocean in order to bring two nations more closely together.

At this present time there is nearing completion a $75,000,000 suspension bridge across the Hudson River connecting New York City with the municipalities opposite on the New Jersey shore, all for the purpose of saving seven minutes over ferry time. No one questions the expense. It is considered a good investment.

The same amount of money (15 million pounds) would build an airship bridge across the Atlantic Ocean with daily service in both directions. For the Atlantic traveller such a bridge would save ten times as many hours as the Hudson bridge saves minutes. And it would be a profitable investment also.

If it is worth while to make it easier for the Gothamites to get to Jersey, how much more important it is to make it easier for the Old World to understand the New World, and conversely.

Here is an opportunity that would challenge the courage of a Francis Drake and merit the favour of a queen like Elizabeth. It would be Gladstone's dream of " hands across the sea " realised.

It has already been demonstrated that no one world state can prosper by itself alone. They are all in trouble now, the world over—population of cities increasing faster than the opportunity for employment—charity and the dole system being substituted for wages—men of families asking the very pertinent question, " How can I earn an honest living? "

Unquestionably there are certain fundamentals in the world situation which must be corrected before prosperity can be placed on a sound and substantial basis. As some economists point out—the mal-distribution of gold; the tendency to divert too large a portion of current surplus to payment of war debts, which in some instances amounts to partial sequestration of actual working capital; the building of extreme tariff walls which tend to separate the different countries into hermetically sealed compartments—all complicate the situation. These and other influences are impediments to international trade and constitute the greatest obstacles in the way of commercial recovery.

Political Significance

Now airships in themselves will not solve these many problems growing out of chronic economic depression. But if in the process of their international application they are instrumental in planting the germ of " live and help live " their mission will not have been in vain.

Perhaps airships have a political significance as well as an economic usefulness. If so, may their destiny be determined by constructively-minded people with social intelligence enough to recognise the fundamental truth that no nation can afford to plan solely for its own aggrandisement without consideration for the interests and welfare of other nations.

May those who oppose such friendly considerations take warning, that, while nations linger in narrow isolation, science has been making wonderful progress, putting at man's disposal tremendous powers that may be used either for constructive or for destructive purposes.

And may we all accept humbly last New Year's Greeting from former Premier Hamaguchi of Japan:

> "The discrepancy between man's progress in his control of nature and in his control of himself has been widening. While new scientific devices bind the world into an inseparable whole, the peoples of the globe are far from being united in one circle of cordial friends.
>
> "Moral sense must be elevated, that spiritual progress does not lag behind scientific and mechanical progress. I deem it imperative, in order to attain this object, that the statesmen of all countries should renew their efforts to elevate the standard of international relationship—to make it a veritable association of gentlemen.
>
> "In the fraternity of gentlemen there can be no prejudice and no affront—only mutual trust and respect."

Let us strive that the airship may become an International Symbol of mutual trust and respect!

APPENDIX

PRESSURE IN AIRSHIPS*

There is pressure in every airship. This chapter discussed its profitable utilisation and the advantages accruing therefrom. The type of lighter-than-air craft whose shape is maintained solely by internal pressure is often called "the Pressure Airship." In this type of airship the contraction and expansion of gas with change of atmospheric conditions is compensated for by the air-filled ballonets. The internal air pressure is maintained by blowing air in the ballonets raising the air pressure therein slightly above atmospheric. The air pressure acts on the movable ballonet diaphragm, thereby increasing the pressure in the gas container and producing tension in the outer cover.

For purposes of analysis this tension is usually considered as composed of two components: longitudinal, acting in the direction of the ship's axis; and transverse (or hoop) tension, acting in the plane perpendicular to it. If an airship were built as a perfect sphere, then the longitudinal component of pressure would be equal to transverse, but as long as aerodynamic requirements dictate a slender, elongated shape with much larger radius of curvature in the longitudinal direction than in transverse, the longitudinal component of pressure becomes smaller than the transverse. Each one of these components performs a well-defined function. The transverse component of tension retains the shape of cross section, which will be circular in case of an airship subjected only to internal air and gas pressure and loads distributed uniformly around the circumference. The longitudinal component of tension due to pressure maintains the longitudinal shape of an airship. When the airship is built of materials that cannot resist compression loads, such as the non-rigid airship, this longitudinal tension component should be always of such magnitude that the tension due to it exceeds the compression imposed by either static or aerodynamic loads acting on the hull. This consideration determines the value of internal pressure to be used in the hull.

It may appear that the internal pressure should be of considerable magnitude to resist these loads, but actually due to large cross sectional areas the pressure required in the case of non-rigid airships is, in general, of magnitude of $1\frac{1}{2}$in. H_2O, or approximately only .37 per cent. higher than the standard atmospheric

* By W. A. Klikoff, Aeronautical Engineer, Aircraft Development Corporation, Detroit, Mich. Presented at the National Meeting of the A.S.M.E., Aeronautic Division, in Baltimore, May 14, 1931, and reprinted here through the courtesy of Mr. Klikoff and the American Society of Mechanical Engineers.

pressure. Such a small pressure can be very easily maintained mechanically, but is also easily subjected to atmospheric variations.

This small increase of pressure corresponds approximately to only 2°F. change in temperature and 0.11in. of Hg. change in pressure, or 100 feet change in altitude. This comparison shows the sensitiveness of pressure to outside atmospheric conditions and the necessity for careful handling.

Maintenance of Pressure

The excess of pressure is handled by automatic valves which tend to release the air from the ballonets in case of gas expansion, and at the present time they have reached such a degree of development that no particular attention is attached to this phase of the problem. The capacity of valves is usually designed for maximum desirable rate of ascent and the valves are set in such a manner that air valves open first and the gas valves follow, so as to preserve gas as much as possible. Manual control of the valves is provided to take care of possible failure of automatic features.

The means of supplying internal pressure have not reached such a degree of perfection as the means of releasing it, and at the present time are rather cumbersome. In non-rigids the pressure is usually maintained by scoops which are lowered manually in the slipstream of propellers. This manual control has the disadvantage of constant attention on the part of the pilot. The drop in pressure to or below atmospheric will cause the collapse of envelope and the necessity of abandoning the forward speed, and will put the airship at the mercy of the winds like a free balloon. The maintenance of too high a pressure produces high tensions in the fabric envelope, causing a more rapid deterioration.

The semi-rigid airship was evolved to relieve tension load in the fabric, and part of its ability to withstand outside bending moments is achieved by the introduction of a rigid keel capable of carrying a very high percentage of the bending load.

In the case of semi-rigids, the pressure is often maintained by means of dynamic scoops which are located in such places on the hull that they automatically scoop up air in the case of forward motion, producing higher internal pressures in case of higher speeds. This arrangement has the disadvantage that if the scoops are not properly located they may be blanketed somewhat in some of the manœuvres, reducing the delivery of air. In addition the scoops become inoperative when the forward speed of the airship drops to zero. In this case the pilot has to rely on mechanical blowers which should always be ready to be started for this purpose. In the hangar, or when manœuvring on the field, the blowers are the only means of maintaining pressure. Being manually controlled, they require constant attention. These factors tend to make the maintenance and operation of present fabric-covered pressure airships troublesome.

The opinion is often expressed that rigid airships are independent of pressure. This opinion is erroneous because the rigid airships are not. They only tend to fly under such conditions that pressure inside is near atmospheric and a series of openings are provided to keep internal pressure as close as possible to atmospheric. Failure to do so may lead to disaster. Some of the rigid airships tend to utilise the effect of pressure for the support of fabric or other purposes. For instance, the British airship, the R.101, was normally operated under slight positive pressure to reduce flapping of fabric covering. Openings in the envelope to satisfy these conditions were provided.

Pressure as a Design Factor

The question arises. If pressure is such a cumbersome factor requiring so much attention, then why use it at all? Why not eliminate it entirely and

build airships perfectly independent of pressure? The answer is, internal pressure is always present even in case of conventional rigid airships, where it is often not used to any advantage, and with present types of design may constitute even a liability. The pressure that is referred to in this case is the gas head pressure. The pressure within a gas container increases upward due to the difference of the densities of air and gas. This property of gas is called " gas head," which is exactly similar to " water head " we have to deal with in hydraulics, but of an opposite sign.

If we call h the head of gas measured upward, and k the unit lift of gas, the pressure due to gas head becomes evidently kh.

This pressure produces constant longitudinal force which in case of fully inflated circular airship is

$$K\pi r^2 h$$

where r is the radius of cross section.

The pressure due to gas head increases toward the top of the airship, therefore the resultant of this longitudinal force acts above the centre line, which usually coincides with the neutral axis of the airship. Consequently it will tend to produce a hogging bending moment which for fully inflated ship is equal to

$$k\pi r^3 h/4$$

The values of longitudinal forces and bending moments for sections not completely filled can be found in text books on airships.

This hogging bending moment and longitudinal force, due to gas head pressure, is present in all airships. In rigid airships there exists another factor due to gas pressure. Whereas in non-rigids the transverse component of pressure produces uniform transverse tension in the covering, in rigid airships this transverse component acts as a side load on longitudinals, complicating their design by loading them with side load combined with direct stresses due to bending of the whole airship. This loading condition of longitudinals tends to explain why gas pressure is often called a liability in the case of conventional rigid airships.

The present large airships reach such large proportions that the gas pressure factor is becoming of primary importance. The diameter of modern airships has already reached 132 feet. In this case the pressure due to gas head at the top of the hull at the maximum section becomes for a helium filled ship:

820lbs. per sq. ft. or 1.57ins. H_2O.

The total longitudinal force becomes 57,000lbs. and the hogging moment due to it 950,000 foot pounds.

These gas head pressures, due to properties of lifting gas, produce forces and moments reaching such magnitudes that the airship designer should undoubtedly try to utilise them as much as possible to his advantage. The longitudinal force is the most helpful one because it tends to produce a uniform tension throughout the structure, and all materials used in airships can carry much higher tensile loads than compression loads. It will be of interest to study the help that could be derived from the longitudinal tension on the hull due to pressure.

Let us consider an airship whose cross sectional area of metal used is A, which is distributed uniformly around the cross section, then the moment of inertia of this cross section is $Ar^2/2$, and if this airship is subjected to a certain longitudinal force P and bending moment M, then the maximum compressive longitudinal stress will equal

$$S = P/A - 2Mr/Ar^2$$

Assuming, as in the case of the non-rigid, the outer covering incapable of carrying any compressive loads or limiting the value of stress, $S=0$, then solving the above equation we obtain the critical value of bending moment in relation

to longitudinal force $M/P=r/2$. If the non-rigid airship is full of gas and is subjected to pressure due to gas head only, then the relation of gas pressure bending moment to longitudinal force due to gas pressure

$$M/P=kr^4/4kr^3=r/4;$$

or the value of hogging bending moment can be doubled before compressive loads will occur in the fabric and the airship could carry sagging bending moment equal to three times the gas pressure moment without having any longitudinal folds in the fabric.

Introducing internal pressure higher than the pressure due to gas head, such rigidity of hull can be obtained that very severe bending moment can be carried by the hull, which is exactly the practice followed in non-rigid airships.

It will be of interest to arrive at actual figures to determine what is the value of internal pressure required in modern airships to resist bending moments. Take, for instance, the case of the British airship R.101, which was constructed recently in Great Britain and which was destroyed with great loss of life in France. During the inquiry of causes of this disaster, and previous to that, the designers have released more reliable information about this airship than about any others recently built.

This airship was 732 feet long, 132 feet in diameter, and had an air displacement equal to 5,600,000 cu. ft. The arbitrary value of the maximum aerodynamic bending moment to which this size of airship would be subjected is

$$M=.02\ (\rho/2)\ V^2\ (\mathrm{Vol})^{2/3}\ L^*$$

or at 75 m.p.h. at sea level,

$$M=.0000237\times 110^2\times 31{,}000\times 732=6{,}640{,}000 \text{ ft. lbs.}$$

Assuming that gas pressure bending moment resists all the static loads, then to counterbalance the effect of this aerodynamic bending moment the longitudinal force due to internal air pressure should be

$$P=P\pi r^2=2M/r;$$

and internal pressure

$$P=(6{,}640{,}000\times 2)/(3.14\times 663)=14.7 \text{ lbs./sq. ft.}=2.82\text{in. } H_2O.$$

It can be noticed that by increasing internal pressure only 180 per cent. above the pressure which is already present on top of the ship, due to gas head, all the compressive stresses which would appear in the hull due to the action of this severe aerodynamic bending moment will be eliminated. This computation does not mean that all the stresses will be eliminated, they will appear on the tension side, but as long as materials used for present airships are of such properties that they can resist tension from 50 to 100 per cent. better than compression, the advantage of utilising the internal pressure can clearly be seen.

The fact that materials should be always utilised on the side on which they are most efficient has long been recognised by the structural engineer, who in suspension bridges utilises the high tensile value of the cables, and in concrete structures utilises the high compressive value of concrete.

Design Conditions and Factors of Safety

In the present design of rigid airships a rather peculiar system of factors of safety is adopted. Factors of safety of 4 and higher are used for static loads, but when the aerodynamic loads are superimposed then the designers do not increase the structure in proportion to increase of load, but increase the structural strength only to some extent which causes decreasing of the factors of safety. This practice is justified by the fact that conditions of superimposing of both types of loading occur less often, and the effects of higher loads on the structure will be less. For this reason airship designers are satisfied to drop

* Technical Report §325 National Advisory Committee for Aeronautics.

their factors of safety to as low as 2, and sometimes even smaller for the worst loading conditions. This method of design may give the operating personnel a false sense of security, making them over-confident in the strength of airships under normal flying conditions, and in case of emergency they may treat the airship without due caution, causing perhaps a breakage of structure and severe disaster. Several airship accidents were traced to this cause by some of the experts in their analysis of the disasters.

It must be kept in mind that the nature and magnitude of gusts and other aerodynamic forces are not completely known and will probably never be definitely known, just as the forces due to waves impact in shipbuilding are just approximated from results of years of experience. Airships while floating in a fluid have the advantage of being more easily analysed for aerodynamic loads, due to the fact that air is a more perfect fluid than water, but air has a peculiarity of having very steep rising and descending currents which may not be visible to the eye of the pilot.

Therefore, a somewhat more logical system of airship design would be not to design the airship for too high a factor of safety for average conditions and too low for an extreme condition, but to design an airship for instances for the following conditions:—

1. Adopt a reasonable factor of safety for the worst static conditions, combined with certain usually encounterable aerodynamic loads.
2. Provide enough compressive strength in the airship to be able to carry these loads safely.
3. In flight when the airship is subjected to severe aerodynamic loads, provide the excess strength and maintain the same factors of safety by introducing certain other positive factors of strength, for instance, one which is the most readily obtainable—pressure.

The operating personnel will then know that when the airship is operating under internal pressure the compressive strength is not endangered, the loads are taken through materials in tension—which are known to have much higher strength value than in compression, and the airship can be safely flown through any atmospheric disturbance and can withstand any manœuvres.

When the pressure system is not functioning for some reason or other, then he knows that the airship is not strong enough to withstand severe loads, and should be handled carefully. It should be slowed down, like an ocean liner partially disabled at sea, no excessive manœuvres should be made, and aerological disturbances should be avoided if possible.

If the pressure system is designed with the required amount of care, then the last condition should really never occur in the life of the ship.

Pressure Rigid Airships

The designers of the large metalclad airship have always kept in mind the policy that the system of design just outlined is a more logical one, and have always considered it as an ultimate goal of metalclad airship design and development.*

As was mentioned previously, conventional pressure airships are so dependent on the pressure that a drop in pressure means a loss of shape and inability to proceed at a forward speed, thus transferring the airship to the free balloon class.

This condition is undesirable, and it should be the aim of designers of pressure airships to design the airships in such a manner that they can maintain their shape and proceed at slow speeds at atmospheric internal pressure, using the

* R. H. Upson's paper, "Metalclad Rigid Airship Development," delivered before the S.A.E., February, 1926, gives the original ideas on internal pressure control as applied to Metalclad airships.

internal pressure as auxiliary means of extra strength and rigidity in case of flying at high speeds.

The question arises as to the possibility of controlling the internal pressure. All the disadvantages of the pressure supply system as used in present airships can be easily eliminated if airship designers would only try to follow in the footsteps of the mechanical engineer, who has already solved the problem of pressure control very admirably in power plant installations.

Pressure Control in Power Plants

It is seldom realised to what extent the control of power plants has been taken out of the hands of the uncertain human element by the automatic regulator.

In a typical automatically-controlled power plant installation the regulators control the fuel feed, air supply, furnace pressure and forced and induced fans. All of these regulators are connected to a master control panel, from which they can be controlled. The master control panel is thus the central control station of the power plant, and the operator can control the whole plant from a single source by simply adjusting the setting of all the regulators. Remarkable decreases in fuel consumption and an economy of plant operation are achieved by this method.

Sometimes the regulators are called upon to regulate accurately pressure and pressure differentials to within an error of .001 inch of water column, and in other instances regulate the steam pressures running into hundreds of pounds to within a few pounds limit.

The automatic combustion control is used in the most modern and large power plants, such as the Brooklyn Edison Company Station, Hell Gate Station, Detroit Edison Company Stations, Bethlehem Steel Company power plants, etc.

The application of automatic control is not limited to power stations only, but we find it also applied to coke ovens, open hearth furnaces and blast furnaces.

The mechanical engineer has accepted the automatic regulator and is using it in the industry and is relying on it in complicated installations where slight disarrangement of the system will cause tremendous losses and disorganisation.

Application of Pressure Control to Airships

The airship engineer may just take one single item out of the complicated power plant control system and instal it in the airship, and solve the whole problem of pressure control on airships. This item, the pressure regulator, can be designed to a range of accuracies exceeding considerably the airship requirements, and would tend to make the control of pressure entirely automatic.

Several automatic pressure regulators could be installed in such manner that a drop of internal pressure would cause either immediate opening of propeller scoops, in case of flight under power, or would start the blower motor, which will be kept constantly in warm condition ready to start. It might be even desirable to provide a regulator, which, in case of failure of the pressure system, would switch off some of the engines, thus reducing the speed of the airship to a point safely allowable for operation without pressure.

The operating personnel, with automatic pressure regulators installed, would set the regulators at a certain chosen value of internal pressure. The regulators would take care of variation of pressure by operating pressure-supplying units. All of these pressure-supplying units could be connected to the control car, and any change in their position would then be shown by a signal on the board installed in the control car. Thus all the elements of internal pressure control system could be checked periodically by releasing the pressure and observing their functioning through the signals. Any uncertainty of the system could be immediately adjusted so as to have the whole system in perfect condition in case of emergency.

Proposed Pressure Control in Metalclad Airships

It is recognised by the designers of large metalclad airships that the pressure system should approach perfection as closely as possible, and that automatic pressure regulators should be incorporated as a part of the system. Undoubtedly the whole body of the airship should be made air tight.

This can be attained by providing all the means of access with doors which are pressure tight. This can be readily accomplished, and is not considered a problem of large engineering importance. Then some of the crew and passenger quarters, as well as corridors and means of access to the structure, can be placed in the hull in the air space, which, under certain conditions, will be under slight pressure. This can be also easily achieved and the small internal pressure inside of the airship, of, say, 3in. water, will not be uncomfortable, because this slight increase in the atmospheric pressure corresponds to a change of altitude of only approximately 200 feet, and the human body is known to be unaffected by this change. The whole interior of the ship will be lighted and kept, as mentioned before, under slight pressure when necessary.

If the pressure rises above the design value, then an excess of it will be released by the air valves, the design of which will be very similar to valves used at the present time.

If the pressure drops, then some means should be provided for its replenishment. The main pressure-supplying units will undoubtedly be the dynamic scoops, which are really inward opening valves, located at several points on the hull where the external dynamic pressure due to forward motion of the airship will exceed the internal pressure required for the longitudinal strength. The design of dynamic scoops is a very simple problem, and they will normally be used as the only pressure-supplying units. Their action can be made perfectly automatic, and, with increase of speed, air at higher pressures will be supplied.

In case it should be desirable to supply more constant pressure, irrespective of changes of speeds, or in case of descents under power—when a large quantity of air must be supplied, the propeller scoops located in the slipstream of the propeller can be used. It is proposed to control these scoops by automatic pressure regulators. If the amount of air supplied by the dynamic scoops proves to be insufficient, then the pressure inside of the hull will drop, and the automatic pressure regulators influenced by this drop of pressure will open the propeller scoops.

Mechanical blowers should also be installed to supply air for rapid descent without forward speed, and for ground handling. The blowers should always be kept in such condition that they can be started at short notice and develop the maximum pressure. The blowers will also be controlled by the automatic pressure regulators, which will start them when the system of dynamic and propeller scoops may prove to be inadequate under extreme conditions.

In case of complete failure of the pressure system, recourse may be had to the present rigid arrangement, *i.e.*, opening of certain apertures in the hull, tending to maintain inside pressure equal to atmospheric. Then the airship will assume the same condition as when maintained in the hangar, and will also be able to fly at reduced speeds, as previously mentioned.

Manual control of all the pressure control items can be provided also as an auxiliary to the automatic control.

It can be clearly seen that the proposed installation will take out of the hands of the operating personnel all necessity for constant attention to the pressure system except for routine checking and inspection, and will remove the most important objection to the use of internal pressure as a strength factor in airships.

Types of Airship Structures

After considering pressure as a factor in airship design, it may be desirable to glance over the types of structures used in the present airships. It must be

admitted that the present rigid airship structure is very similar to the familiar airplane " wired frame system " used in the wartime days. The airplane fuselage, built according to this system, had four longerons acting as major structural members, braced by shear wires and covered by doped fabric which, to produce a shape of low resistance, was supported by fairing strips. Only longerons and shear wires acted as structural members, the remainder of the cross section being added only for streamline effect.

The present rigid airship employs very similar arrangement, except that it even complicates it by adding the gas cells and the gas cell wiring. Therefore, if all the elements of the cross section of the rigid airship are considered, it will be found that a large percentage of the total weight is not efficiently utilised from a strength standpoint, but serves auxiliary functions such as gas holding and preserving exterior shape.

Assuming a certain rigid airship and applying to it an arbitrary value of bending moment, it will be found that the stresses on the tension and compression side will be equal, and for comparison it may be assumed that the factor of safety is 4 on the compression side and 7 on the tension side. Suppose the longitudinal force is now introduced of such magnitude that it eliminates all compression loads, then there will be zero stress on the compression side, but on the tension side the factor of safety will drop to 3.5.

From this consideration alone it appears that it is not advantageous to utilise the effect of pressure on rigid airships. This is due to the already mentioned fact that rigid airships do not utilise all the materials disposed around the circumference as load carrying factors. If all the materials employed could be utilised, then the cross sectional area available for load carrying purposes would be increased and the unit tensile stresses would drop. That is exactly the principle used in non-rigid airships, where the whole cross section acts as a load carrying member. This statement is proved by the fact that theoretically in non-rigid airships the same overall efficiency can be reached as in rigid airships. The proper utilisation of the cross sectional area, although handicapped by inability to carry any compressive loads, can be made as efficient as the rigid system of design.

It would appear that the most efficient system of design should utilise the compressive and tensile ability of the cross section to the utmost advantage. Taking the case of the airship just considered, the most advantageous value of internal pressure will be such that the factors of safety on the compression and tension side are equal, or 5.5 for the loading above mentioned. It will be hard to balance the pressure exactly at this point, but this investigation points to an ultimate design of airship which will tend to utilise completely the whole value of the cross section as a stress-carrying member capable of carrying high tensile as well as certain compression loads.

As was already mentioned, the ultimate metalclad airship design would try to approach these requirements. In it the high transverse stresses due to pressure, which are so detrimental to fabric non-rigids, are easily carried by monocoque metal covering. The hull of such a ship should also be sufficiently reinforced in the longitudinal direction to carry appreciable compressive loads. The perfection of this method of construction employing the proper combination of internal structure with stressed skin covering will produce the very efficient large size airship capable of the high speed essential to commercial application.

Conclusion

It cannot be denied that pressure is one of the major factors in airships. It is always present as a gas pressure force. The question is, whether it would be advisable to utilise the pressure as a strength factor or try to combat its effects as much as possible. As long as airships are built of materials which are more efficient in tension than in compression, and pressure provides a factor

which allows carrying all the stresses on the tension side, then it is certainly advantageous to utilise pressure as a strength factor. This can be accomplished by raising the internal pressure higher than the already present gas head pressure value.

The question of control of internal pressure can be solved by an application of modern methods of control already adopted by mechanical engineers.

It is undeniable that from a safety standpoint airships should be built not fully dependent on pressure. The ultimate airship must be designed to be rigid enough at atmospheric pressure for maintenance in the hangar and for slow speed flying, and utilise the pressure only as a positive factor of excess strength to withstand extreme loading conditions. Such an airship in counterbalancing the excessive external loads by internal pressure coincides with the logic of Count Zeppelin, who many years ago said:—

> " The forces of Nature cannot be eliminated, but they may be balanced one against the other "

to serve man's needs.

Discussion

Commander Sir Dennistoun Burney: He personally had always had a very high opinion of the possibilities of the metalclad airship. There had been a great deal of difficulty with the fabric of both the outer cover and the gas-bags of the British airship R100, and he had been forced to the conclusion that they should have to find some solution of the difficulties inherent in a fabric ship before they could produce a vessel which would operate economically. When it was pointed out that there was used, in such a ship, five acres or perhaps rather more of goldbeaters' skin fabric, the thickness of which was little more than that of a pocket handkerchief, and that the safety of the vessel depended upon the gas-tightness of that material, one could appreciate the difficulty of the problem. Another reason why it was important to dispense with fabric was the necessity for increasing speeds. He had never believed that a cruising speed of about 60 or 70 miles per hour would be sufficient for airship traffic. There was no doubt that, for many years to come, the passenger traffic carried by air would be more expensive than that carried by sea, and although there was the appeal of the novelty, there was also the problem of speed and comfort, and unless a very considerable improvement in speed was effected in service he doubted that the airship would be patronised. There was sufficient traffic, and sufficiently rich traffic, across the Atlantic to make the proposition pay, but they were faced with very difficult meteorological conditions, which entailed the westward journey being accomplished at a high air speed, and it was for that reason that he looked hopefully towards large metalclad vessels.

Sir Dennistoun congratulated Mr. Fritsche not only upon the fact that he had been responsible for the construction of the first practical metalclad airship, but also upon the fact that it was the first airship which, on completion, was of less than the specified weight. The future of British airships was being debated at that moment in the House of Commons, and if Mr. Fritsche could have read his paper in the House of Commons he would have rendered great service; though the Royal Aeronautical Society would have had to forego a most interesting evening, Mr. Fritsche would have given some very useful guidance to the House of Commons.

Professor L. Bairstow, C.B.E., F.R.S., *Fellow*: It was a very great undertaking to depart from what might be called the conventional Zeppelin type of airship, with rings, longitudinal girders and shear wires, and to replace the shear wires by a metal skin. Recently in this country Professor Southwell had put forward a theory for the stability of thin sheets, and, without a great deal of experimental work, such as the American authorities had carried out over a

period of seven or eight years, one would feel that the theory showed the application to be impracticable. It appeared that the results of scientific work on metals had a determining influence upon the decision to build a metalclad airship. Had pure aluminium been used, the ship would not have been safe for a sufficiently long period. He gathered from the lecture that the ZMC-2 was a single-cell ship, *i.e.*, that there were no divisions inside the hull, but he gathered also that the larger airship which it was proposed to build, and which was to have a lifting capacity of 100 tons or more, would have a divided internal construction. The departure from the ZMC-2 gave rise to the problem of how to deal with the stresses arising in the structure when one cell was deflated, but the lecturer indicated that those concerned were in a position to deal with it. He asked Mr. Fritsche what was the meaning of the expression "factors of safety" as used in the paper. Reference had been made to a factor of safety of 4 against static loading. If such airships were to travel at a speed of 100 m.p.h., the aerodynamic loads imposed upon them, especially in rough weather, would greatly exceed the static loads. The expression "static loading," as used in the paper, might mean "total load under steady flying conditions," but he asked whether, in such conditions as were experienced in this country, a factor of safety of 4 could be maintained under all flying contingencies, certainly it could not be done in either of the two British airships R.100 and R.101. The idea of a metal covering, instead of fabric, was very attractive, but they, in this country, were not yet in a position to assess the relative merits when all things were considered.

Mr. E. F. Spanner, M.I.N.A.: The paper opened up a new aspect of the problem of rigid airships—although a paper had been presented previously to the Institution of Naval Architects by Baron Rœnne, describing a rigid airship in which it was intended to use a metal skin to enclose the gas. The metalclad airship appeared to be a development of the semi-rigid. The semi-rigid airship had always appealed to him as a very much sounder proposition than the Zeppelin type, because in the former it was possible to put into the envelope sufficient strength to carry the aerodynamic stresses—wind stresses, and so on—and also the weight of the material which normally had to be used in the gas-bags in the Zeppelin type of structure. When the envelope was dissociated from the gas-bag material the envelope became very much weaker. In the metalclad airship Mr. Fritsche had incorporated the external fabric with the gas-bag fabric and had incorporated the structural frame in the shell of the ship, and undoubtedly this represented a very great step forward from the theoretical point of view. He was rather inclined to think, however, that as airships became longer than the small model ship it would be found—as had been found in ordinary surface ships—that there would be rather excessive shear stresses extending to about one-third of the length of the ships from each end, where the shear stresses due to bending stresses and due to actual static and aerodynamic stresses were added together. Another feature of the metalclad ship which appealed to him was its simplicity. He congratulated Mr. Fritsche very heartily upon having produced tight joints in the metalclad ship—a result which he (Mr. Spanner) had thought would be almost impossible. Of course, a bitumastic composition was used, but the production of helium-tight metal joints in the manner described, and so easily put together, was a matter for congratulation. In expressing his appreciation of the trouble Mr. Fritsche had taken in the preparation of his paper, he said he was hoping to find some opportunity of utilising in naval architecture some of the ideas put forward. From the commercial point of view he still considered the airship business to be very speculative; there was no security, and his original opposition to airships had arisen from this lack of security.

Professor C. F. Jenkin, C.B.E., LL.D., M.Inst.C.E., *Fellow*: It appeared to him that, apart from the rings on the inside of the metal hull, there seemed

to be no other internal framework, and he asked if that were so. Referring to Table III, he said that the thickness of the "Alclad" sheets was stated to be .0095in., but in the next section of the paper it was stated that the thickness of the aluminium coating on either side ranged from .005 to .007ins. It appeared, therefore, that the two coatings were thicker than the finished sheets, so that presumably one of the figures was a misprint.

Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., *Associate Fellow*: He would like to comment upon the very small fineness ratio chosen for the first metalclad airship. He did not know that there was much reliable information available at the moment from which one could deduce satisfactorily what fineness ratio would give the least drag, but he had noticed that the fineness ratio in the proposed new ship was considerably greater than in the first one. He wondered whether Mr. Fritsche was proposing to increase the fineness ratio partly because he expected a finer ship to give a smaller resistance coefficient. In this connection, he had been able to deduce from the data given in the paper that the resistance coefficient of the ZMC-2 was 0.0192 and that for the R.100 was 0.0118; in other words, the finer ship appeared to have a resistance coefficient 60 per cent. of the resistance coefficient of the other. He asked whether the figure of 0.0192 confirmed the results of wind tunnel tests, or whether such tests had indicated a much lower resistance coefficient for the ZMC-2 than had been obtained on the full scale; and if the latter was the case whether it was partly the reason for the choice of such a low fineness ratio for the ZMC-2.

Mr. N. S. Norway, B.A., *Associate Fellow*: With regard to the maintenance of the pressure in a metalclad airship, in the R.100 when over the St. Lawrence a rate of rise of about 3,000 ft. per minute was experienced during a thunderstorm. In a thunderstorm of that sort there might equally occur an involuntary descent of something like 3,000 ft. per minute, and he supposed that in such a case one would shut off the engines in order to reduce the aerodynamic forces on the ship. If the metalclad ship experienced a sudden fall of that sort, he could not quite see how one would be able to keep up the internal pressure, upon which the strength of the ship partially depended. It seemed to him that if there were a fall of anything like 3,000ft. per minute, in an airship of 7 million cu. ft. capacity, it would be necessary to pass an extremely large quantity of air into the hull every minute, so that there must be available in the ship an air pump with some hundreds of h.p. in order to meet such a contingency. He asked Mr. Fritsche whether precautions were, in fact, taken to cater for such a fall.

(*Contributed*): He would like to detail a little more clearly the pressure enquiry which he raised at the lecture. It has been established that in a relatively mild thunder cloud an airship can be driven up at over 3,000 ft. per min. This case must clearly be taken as a minimum basis for design in future. Does it follow that in a similar disturbance an airship can be driven down at the same rate?

If so, in order to maintain the internal pressure in a 7 million cubic foot metalclad airship, no less than 630,000 cubic feet of air must be pumped into the ship every minute against the internal pressure of approximately 15lbs. per sq. ft. This would be a formidable blower problem on dry land. He did not think that one would care to blow air into a ballonet at a speed of more than 30 ft. per sec., in which case the sectional area of the air ducts at some point would seem to total no less than 300 sq. ft. About 450 b.h.p. would be required.

Is it wise to rely upon scoops in the slipstream to meet this case? In such circumstances one feels that the pilot must be free to shut down his engines if it seems advisable, without impairing the strength of his ship by doing so. On the other hand, it appears that if a separate blower installation be carried to meet this case a considerable handicap will be imposed upon the ship.

It would be most interesting to hear from the lecturer whether he considers that a rate of fall of this magnitude should be accepted for design or not. In a fabric covered ship the case can readily be met; in a metalclad, not quite so readily. The point is of especial interest as it appears that this is the one weak link in the chain of safety features which the metalclad design presents to airship builders.

In regard to the transverse frames, in this country they had not been very successful in producing a design of " resilient diaphragm, allowing for deflection of the diaphragm should a deflation occur, yet sufficiently rigid to restrain surging of the gas while in flight." In the early days of the R.100 design he investigated a great number of diaphragm designs—tight wires, slack wires, wires with springs, wires with ratchet escapements, wires woven together like a spring mattress. He did not say that the problem was insoluble, but he believed that the lightest and most satisfactory transverse frame for ships of any diameter is the shallow girder frame braced with a simple radial system of steel cable. The R.100 design has certain defects; the defects in the R.101 design were, in my opinion, more fundamental and less easy to rectify. It would appear that surging is definitely less with the taut wire, shallow frame design. The deep frame ship is superficially attractive; they must wait for the production of the ZRS-4 for proof that it is really so in practice.

In regard to weight, the comparison of the M.C.50 design with R.100 is most interesting. The fixed weights of R.100 as at the final lift and trim trial before the first flight were 66 per cent. of the gross lift, 100 per cent. full of hydrogen. The fixed weights of R.101 were 76 per cent. in similar conditions. These weights include in each case an elaborate accommodation for 100 passengers. In addition, the longitudinal strength of R.100 is such that she is roughly 30 per cent. stronger than the criteria laid down for the design competition of an airship for the U.S. Navy of 1928. This may affect the comparison with the M.C.50.

On a similar basis the weights of the M.C.50 appear to be about 52 per cent. of the gross lift on hydrogen. If this estimate can be achieved in practice with a large ship, and the lecturer has shown that it can be done with a small vessel, it constitutes a very powerful argument in favour of the metalclad ship. The addition of the extra frames and the extra longitudinal strength of the M.C.50 design to bring it into accordance with the R.100 would still leave a considerable balance of weight in favour of the metalclad, assuming that the accommodation for passengers and crew is the same in each case. If this estimate is correct, in fact, it would appear that a ship could be built to the R.100 specification considerably lighter on metalclad lines than upon the design that was actually built.

Experience upon weight estimates for rigid airships in this country, however, had led him to the belief that no estimate prepared from any source other than the working drawings can be regarded as even approximately reliable, and invariably errs upon the side of lightness. Their first estimate for the fixed weights of R.100 was 51 per cent., made in 1924, and it might fairly be argued that this is the figure that should be used for comparison with the M.C.50 estimate.

Might he, in conclusion, offer his most sincere congratulations to Mr. Fritsche upon the advances which he has made in the design of airships? He believed that he was on the right lines, and that the airship of the future will trace its descent more from the M.C.2 than from any other airship that exists to-day.

Capt. F. L. M. Boothby, R.N., C.B.E., *Fellow*: His only regret was that the late Wing-Commander Usborne had not been able to hear this lecture, because probably he had the most progressive brain in regard to airships in this country. When he was Captain of the Naval Airship No. 1, he had hoped that some day there would be developed a metal covering for airships. He would have been pleased to have noted the great progress that had been made. At the

time when he had been working on airships there had been no prospect of developing a metal suitable for covering the small ships then being designed, but he had made calculations as to the size of ship which would warrant a steel covering, and had, of course, concluded that such a ship would have to be a very big one. Captain Boothby added that he personally had always felt that a metal covering—which all agreed to be necessary for airships of the future—would have to be in the form of a metallised fabric, but after hearing the results of the tests on "Alclad" metal, they could wash out the idea of using fabric and conclude that all-metal outer covers would be used. He asked if Mr. Fritsche did not consider that it seemed almost like "gilding the lily" to use helium in the metalclad airship. If hydrogen escaped from such a ship and was set on fire it would burn in the manner of a gas jet and the heat would be carried away as in the case of a gas jet and eventually the flame could be put out or would blow out. At the Linde-Francke-Cano Works at Munich, where hydrogen was made before the war, there had been numerous leaks in the plant, and care had been taken to set them alight so that no explosive mixture could form, and the same principle might apply to metal airships. He asked Mr. Fritsche how the metalclad airship was filled. With regard to the maintenance of pressure, he personally believed that that would be greatly arrested by the use of swivelling propellers, by means of which one could slow down the forward speed of the ship, and at the same time would have the full engine power available not only to check the descent or ascent, but also to blow air into the ship.

Mr. F. Duncanson, B.Sc., *Associate Fellow*: A great step in the development of metal airships was the utilisation of internal pressure to retain and augment the structural strength. It was interesting to know that the proposal was made some 30 or more years ago by Professor Perry, in connection with structures of thin walled steel cylinders subject to internal pressure, and the application to aircraft was suggested in his book on applied mechanics. It seemed to him (Mr. Duncanson), however, that it would be advantageous not to rely upon pressure but to have some other means of obtaining the initial tension on the skin. As the size increased, the ship became more efficient and, therefore, he suggested that perhaps in future more material could be put into the structure to increase its durability. He asked how airship structural weight varied with size. In the case of heavier-than-air craft the weight increased as the cube of the linear dimensions; what is the law connecting structural weight with linear dimensions in the case of an airship?

Mr. H. B. Wyn Evans, M.B.E., Hon.R.C.N.C., *Associate Fellow*: He expressed the hope that his remarks would not be deemed to indicate undue pessimism on his part concerning the future of airships. He felt sure they should be able to surmount all difficulties eventually, but he was rather inclined to think that they were trying to run before they had learned to walk. He believed they had tackled successfully the majority of the constructional difficulties, and the successful results obtained by Mr. Fritsche should be regarded as representing another step on the road to complete success. The statement made by the late Colonel Richmond in his Address to the British Association in 1930 that "Filled with helium, driven by engines burning heavy oil fuel and sheathed in metal, there is no reason why the airship should not become the safest form of transport yet devised," was true so far as it went, but the criterion of successful airship operation, however, was speed, both from the economical and the safety points of view. It was speed that was required to give the momentum necessary to overcome disturbances—they had been forced recently to realise what these disturbances meant—and until a sufficient degree of speed was attained he believed airships could be considered only as fair-weather craft. They were relatively huge structures, and without high speed must be at the mercy of any powerful disturbances. All airships had experienced this at one time or another and they knew the suddenness with which an airship passed from a condition of reasonable

elevator control to none at all. He appreciated that this attainment of greater speed would mean sacrifice of useful load or the development of units of still higher power/weight ratios than those in existence at present. As engineering structures, airships commanded our admiration, but as useful aircraft they would not in their present form do so until they could efficiently carry many more horses.

Major F. A. Bumpus, B.Sc., A.R.C.S., *Fellow*: He had had the privilege of visiting Detroit when the ZMC-2 was under construction, and had been taken inside it by Mr. Fritsche while it was being inflated and deflated. It was a most interesting experience, and the feature which had perhaps impressed him most of all was the fundamental difference in the character of the shell when inflated and deflated. In the pictures which Mr. Fritsche had shown of the shell during construction, the wrinkles were very noticeable, but there were no signs of such wrinkles in the photographs of the completed ship; when the ship was inflated it looked like a ship, and the experience with it during the last 12 months or so had proved that it was a ship. Those who were not directly connected with airships regarded them perhaps with a certain amount of scepticism; he certainly had done, but if one tried to analyse the reasons for that scepticism it would be found that a very large proportion of them was really associated with the troubles and difficulties connected with fabric. The metalclad ship was, at any rate, an engineering proposition, and while undoubtedly it introduced new problems and new difficulties, he believed that most engineers would feel that if those difficulties and problems could be overcome, then Mr. Fritsche and his associates had produced something which was in a very different category from anything of which we had previous experience. When one read the paper and realised how carefully and thoroughly the engineers concerned had made their investigations before constructing the ship, spending some seven years in finding out and enumerating the difficulties, and then tackling them one by one, and solving each problem in turn—and this was specially to their credit—one must be impressed.

After all, the full-scale ship provided the only true test as to whether the proposition was or was not a practical one, and he gathered that Mr. Fritsche's aim at the moment was to justify such an experiment. He personally felt, after reading the paper, that Mr. Fritsche had made out his case and would say to him "Go ahead," and he only hoped that the powers in the background—upon whom manufacturers must depend for ventures of this magnitude—would reach the same conclusion and enable the Aircraft Development Corporation to proceed with the proposed new ship.

Mr. H. Bateman, A.C.G.I., B.Sc., D.I.C., *Associate Fellow*: He would like to say something about the aerodynamics of the ZMC-2. Mr. Ralph Upson had published the results of tests on the model in the American variable density wind tunnel, and had obtained remarkable drag coefficients, much lower than those of British airships. He asked, therefore, whether those results had been found to be comparable with those obtained on the full-scale airship. It would appear that if the drag coefficient was really so low there would be no need to have a larger fineness ratio in the larger ships. If the fineness ratio was increased there would be increased bending moment, there would be more gas compartments, greater weight/lift ratio and more difficulties with regard to surging—all these factors should be quite small with the small fineness ratio of 2.8 to 1 in the existing ship. Reference had been made to factors of safety of "4 and 5 under maximum adverse conditions" and Mr. Bateman asked what exactly was meant by that expression. It seemed to him that it depended a great deal upon the optimism of the designer, and that no two designers would have exactly the same ideas about maximum adverse conditions. He recalled that the R38 was designed to withstand maximum adverse conditions with regard to the static bending moments of the ship, but other people had considered adverse

maximum condition to be rapid reversal of the rudders, and it was found then that the factor of safety of the ship was slightly less than 1—and the ship had broken.

Wing Commander T. R. CAVE-BROWNE-CAVE, C.B.E., M.I.Mech.E., A.M.Inst.N.A., *Fellow*: The airships with which it is natural to compare ZMC-2 are the non-rigids of about equal capacity. The comparison shows in favour of ZMC-2, although she uses helium. It must, however, be remembered that if our war-time non-rigids could have taken advantage of all that is now known of shape and stability and had carried present-day engines, their performance would have been immensely better than it was.

The step from the small metalclad to the large one appears to involve many difficulties about which one would naturally be uneasy were it not for two factors: One, the magnitude of the difficulties already successfully overcome; the other, that the performance of the airship was as good as that forecast, and this indicates that those financing the development have sufficient sober judgment to go forward without having to be tempted by optimistic estimates.

In larger airships there will be a greater difference in the distending pressure at the bow and at the stern when pitched. At higher speeds greater internal pressure is necessary. In a system which is more and more dependent on pressure it may be worth while considering a still further increase of pressure in order to gain further advantages which could not be realised in a rigid airship of conventional design.

If an airship of 150 tons displacement were made capable of withstanding an internal pressure of, say, 11lb./in.^{2}, she could, without discharging air or gas, rise 2,000ft. above the height at which she had zero pressure and at the top of this rise would be 10 tons "heavier." Such a ship if ballasted to be in equilibrium at a flying height of, say, 2,000ft., and at half her permissible pressure could be flown without any use of blower, scoops or valves at any height within 1,000ft. above or below 2,000ft. and with one novel advantage. The weight of the ship and her contents being constant, she will be five tons light if forced down to 1,000ft., and five tons heavy at 3,000ft. This might greatly simplify handling, unless it was found that the ship was aerodynamically difficult to control when light or heavy.

It may be found that with this automatically-corrected heaviness or lightness the ship cannot in bumpy weather be kept within 1,000ft. of her normal height. For rapid descent the present blowers and scoops, if now sufficient, would be equally satisfactory for the high pressure ship. For rapid ascent the greater pressure would give greater discharge through valves of given size, and, therefore, a greater safe rate of rise.

One paragraph about helium may perhaps be added. Helium has always been advocated by those who have it to sell. To the lay mind the use of helium immensely increases safety. In reality this is very doubtful. Imagine R.101 leaving for a long flight which she could achieve with a reasonable margin if filled with helium and where safety is of specially great importance. Will any responsible airship captain write a reasoned note to the Royal Aeronautical Society and say that he would sooner start such a flight with helium than with the 15 tons extra lift he would have with hydrogen?

Mr. E. WIESER, B.Sc., D.I.C.: The opinions on the question of most efficient fineness ratio are controversial; the Zeppelin Company claims that the fineness ratio of six or more is the most suitable, while the lecturer prefers $4\frac{1}{2}$. He would like to know whether, in building the first experimental metalclad ship of a fineness ratio of 2.83, the main point the designers were aiming at was that of least resistance, or whether it was rather a structural requirement; as, in the metalclad ship, good structural efficiency requires a fairly short and compact hull.

He understood that the secondary forces which tend to distort the section from its circular shape are taken care of largely by the double curvature of the hull's

surface. In other words, this means that the radii of longitudinal curvature should always have a finite value, on the magnitude of which depends the extent to which the longitudinal tension balances the internal pressure. The effect of the parallel middle body as regards resistance and its influence on cost of construction are fairly understood. It seemed to him that in the metalclad ship it would not be possible to have parallel section at all on principle grounds.

In the metalclad ship neither the plating nor the frame is structurally self-sufficient, but each supports and reinforces the other. In case of a commercial metalclad ship of, say, $7\frac{1}{2}$ or 10 million cubic feet capacity and of fineness ratio of $4\frac{1}{2}$, as the lecturer indicates, he would like to know whether there would be any difficulty in building the unbraced triangular transverse frames of such large diameter, having adequate strength, and which would be sufficiently light.

As to the weight, the difference between a ship of 200,000 cubic feet and 5,000,000 cubic feet is so great that, without having figures relating to actually built ships of intermediate size, the calculation of the weight of the whole ship, in order to compare it with present fabric-covered ships, can only represent a rough approximation. The lecturer quoted the last sentence of a paper given by the late Col. V. C. Richmond. In the same paper* Col. Richmond says:

"If it be supposed that, in the case of R.101, the whole of the weight of the longitudinal system of the hull framework, the weight of the supporting nets for the gasbags, and the weight of the outer cover and its supporting girders be allotted to a duralumin sheath, this could not be more than one two-hundredth of an inch thick."

He would like to ask the lecturer what would be the average thickness of the metal skin of a proposed ship of 5,000,000 cubic feet capacity.

From a structural point of view it seems to be necessary that the tail of the metalclad ship should be rather full, so it cannot be more pointed. This affects the flow over the stern and increases the resistance.

Mr. JOHN L. HODGSON, B.Sc., M.Inst.Mech.E., Assoc.M.Inst.C.E., *Associate Fellow*: One feels as one reads through this fascinating paper of Mr. Fritsche's how easy it is to build airships when one goes about the matter in the dogged, logical and sensible American way. And yet there is an element of luck in the success or failure of even the best-laid plans. Mr. Fritsche's scheme at its inception some ten years ago was essentially almost as hopeless as that of Schwartz in 1897, owing to there being no suitable metallic material available at the time of its inception for the plating of his ship. The chance invention of "Alclad," a material which stands up to corrosion far better than duralumin, made all the difference. For airships of colossal dimensions some form of rustless steel might even then have been available 10 years ago. But the jump from the small experimental aluminium ship that was partially built and then abandoned to ships of colossal size plated with rustless steel would probably have proved commercially impracticable.

The inflated "Alclad" metalclad airship seems at one bound to have brought airship construction from the realms of romantic endeavour into the realms of sober and practicable possibility.

There are a few questions which the writer would like to put to Mr. Fritsche:

(1) Would not the ingenious rivets be far stronger, less abrasive to the gasbags, and still more effective in sealing off the gas if their heads were dome-shaped instead of square? One would never think of building even a tramp steamer with such crude riveting.

(2) Why is not hydrogen mixed with helium so as to secure a greater lift?

(3) What are the gasbags made of, and what would be their permeability if a mixture of hydrogen and helium were used?

* "The Development of Rigid Airship Construction" by Lieut.-Col. V. C. Richmond, O.B.E., B.Sc.; the Paper was read before the British Association, at Bristol, on September 8th, 1930.

(4) What is the special advantage of the eight fins on the tail?

(5) In view of the difficulty of controlling airships when the nose is deflected even a few degrees downwards out of the line of flight (especially if they are nose heavy), why is Mr. Fritsche's new airship fitted with bow elevators? These have been found absolutely necessary in the analogous case of submarines.

Mr. Fritsche's fascinating paper is to the writer much less impressive when it dives down from the skies into the troubled seas of Economics and Imperial Policy. It suggests that they in England should construct airships in order to increase their foreign trade. Yet it is becoming increasingly manifest that the great manufacturing nations should absorb their surplus production in giving leisure and enjoyment and the opportunity for culture to their own people instead of competing madly in distributing their products to the far ends of the earth. Build airships by all means. But build them for the same reason that they build gliders—because they enjoyed flying in them—and not as shuttles to carry bagmen and samples to level down and paralyse the diverse cultures of the world.

Together with the other great manufacturing nations, Great Britain has to learn how to use its vast productive and constructive potentialities for the benefit of its own people, and not to keep these idle when neither war nor foreign trade conditions permit them to fling their wealth across the seas. Mr. Fritsche states that in order to supplant the growing economic distress " it is essential above all things that the product of labour should find ready distribution." It seems to the writer a pitiful parody on the real necessities of the case to suggest distribution by airship instead of by a universal increase of credit facilities; that is by steady *increase* (instead of *decrease*) in wages and salaries. The economic theories of Henry Ford in America, and Bata in Czecho-Slovakia, crude and unimaginative as they seem to the writer, appear to him to be sounder than this!

Mr. T. S. D. Collins (Royal Airship Works, Cardington): At the outset he wished to state that the criticisms which he would make are offered in the spirit in which they are called for by the author.

(1) In Table 4 are shown comparative weights of the fabric-covered R.100 and a metalclad airship M.C.50, which has not yet been built. It is considered that such a comparison is not real unless the two types of airship are designed to meet the same loading conditions. One of the conditions governing the design of R.100 is that of static loading due to any one gasbag deflated combined with the condition in flight which produces, to quote the British Airworthiness of Airships Panel, " maximum aerodynamic bending moment at full power." Weight is therefore added to the structure of R.100 in order to provide the strength necessary to meet these severe conditions of loading. Moreover, with the R.100, sufficient dynamic lift can be obtained at full power to balance the complete deflation of the largest gasbag.

Is the M.C.50 designed to meet these same conditions of loading? A first reading of the paper appears to indicate that it is not. In the appendix to the paper it states, " when the pressure system is not functioning . . . the airship is not strong enough to withstand the severe loads and should be handled carefully. . . . It should be slowed down . . . no excessive manœuvres should be made and aerological disturbances should be avoided if possible."

He submitted that the circumstances which cause a breakdown of the pressure system or a deflation of a gas cell may require the use of full power in order successfully to combat them. If a gas cell does deflate, the surrounding metal shell has to be capable of withstanding the stresses due to external loading conditions without any relief due to gas pressure. Furthermore, if a gas cell becomes deflated, the flexible diaphragms in the gas chamber referred to will require to be strong enough to take the end pressure of the adjacent gasbags. At a diameter of 132ft. this end pressure will amount to about 25 tons. Since no

wires are used to support these diaphragms, the fabric will require to be very heavy in order to be of adequate strength.

It is therefore felt, in view of these observations, that if the M.C.50 were designed to meet the same loading conditions as R.100 its weight would be much greater. It is interesting to note in this connection that for the Z.M.C.2, the weight of the complete metal cover, with its supporting longitudinals and air ballonets, amounts to 33.4 per cent. of the gross lift. In R.100 the combined weight of the outer cover, shear wires, gasbag wiring, gasbags and longitudinals amounts to 26.1 per cent. of the gross lift. It may also be remarked that the largest gas cell in the M.C.50 is 27 per cent. larger than the largest in R.100. Greater dynamic lift is therefore necessary to help in countering the effect of loss of lift due to a deflated gas cell, and this could not be obtained by slowing down the ship.

(2) One of the troubles of airship operation is due to superheating of the gas. In the fabric-covered airship the air-space between the outer cover and the gas-bags tends to reduce superheating. One of the advantages claimed for the metal-clad airship is that this "Dead air volume," as it is called, is used up to gain increased lift. What of the effect on the superheating of the gas and consequent operational troubles?

(3) He disagreed whole-heartedly with the author when he refers "to a maze of stress-carrying undependable wires." A steel wire is the most efficient form of structural member, its strength: weight ratio being much greater than that of any other type.

(4) He did not wish to enter at any length into the controversy of helium *versus* hydrogen, except to state that if the 200-ton commercial metalclad airship had been inflated with hydrogen instead of helium, its useful load would have been increased by 40,000lbs., *i.e.*, roughly 18 tons.

Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry): He welcomed Mr. Fritsche, firstly as an American aeronautical engineer, and secondly as the representative of a most courageous group of pioneers. Courage of the kind they had displayed, he said, was valued and respected here; their undertaking to construct the type of airship described in the paper, and the care and skill they had devoted to the work, was deserving of the very fullest tribute that could be offered.

The discussion upon the paper had been representative, because it had been contributed to by those who built airships, those who used them, and those who carried out the scientific experiments in the wind tunnels and based calculations upon them. He looked forward to Mr. Fritsche's reply to the rather comprehensive questions that had been put to him.

Discussing the commercial aspect of the airship problem, Mr. Wimperis said it seemed that the airship had a much better chance of "earning an honest living" in the United States than in this country. For civil purposes probably the public would insist upon the use of helium, and if they did they would have to consider the cost of transport of helium to the points at which it was required. Mr. Fritsche had stated that the prices of helium were from $12 to $30 per thousand cu. ft., f.o.b. at the refinery. He had also mentioned a figure of $40 per thousand cu. ft., including freight—which presumably meant internal freight charges in America. Assuming they could obtain helium from America for use in this country, they would have to add the cost of freightage from America, so that that would make it more difficult for an airship to earn an honest living in this country. But whether, owing to difficulties of that kind, services of the future would have to be run from America, or whether they would be run from this country, he assured Mr. Fritsche that any service airships which came our way would be thoroughly welcome; British aeronautical engineers would be almost as glad to see a splendid development of this kind carried on by their cousins across the Atlantic as they would be to carry it on themselves. British aero-

nautical engineers had received so much assistance, particularly on the scientific side, from American investigators that they felt a camaraderie, to which he was very glad to have the opportunity of giving expression.

In conclusion, Mr. Wimperis proposed a hearty vote of thanks to Mr. Fritsche for his paper.

The vote of thanks was carried with acclamation.

Reply to Discussion

It should be emphasised that the lecturer is but the spokesman of that group of co-workers whose patience and ingenuity made the success of the first metalclad possible.

Sir Dennistoun's expression of faith in the metalclad is most gratifying. His unsparing effort on behalf of lighter-than-air development in England has been and is an inspiration to us in America.

In replying to the many questions arising out of the discussion, it would be deleterious to the development of the metalclad and a reflection on its proponents to assume that precise and unalterable answers can be and are immediately available. Science tolerates no such dogmatism. Once a problem is precisely defined, however, its solution is one-half accomplished. It is in the definition of a problem that the critic performs his most useful service.

Replying to Professor Bairstow, it should be admitted that the progress in metallurgy has made large metalclad airships practicable and a more intimate knowledge of metals will still further facilitate the development of metalclad airships.

Professor Bairstow, by referring to instability of plating evidently means the instability under compressive loads. It cannot be denied that thin plating, if considered alone and without the supporting effect of internal pressure, will carry but slight loads in compression or in shear. In the ZMC-2 the thin plating is supported by very light longitudinals and this combination carries the compressive loads. With this type of construction there are quite large unsupported panels of light plating and due to its great curvature in both the longitudinal and transverse directions there is considerable slack plating which does not make a very efficient structure for carrying shear stresses without internal pressure.

During construction of the ZMC-2, especially during the turning of the two sections, comparatively low shear loads caused large shear wrinkles to appear in this slack plating. It was observed that where the curvature was the greatest the shear wrinkles were also the largest. All these wrinkles in the plating disappeared when the loads were removed, as in no case were the loads large enough to deform the supporting structure or cause permanent folds in the plating.

The designers of the metalclad are satisfied that the type of construction as used in the ZMC-2 will carry the required compressive loads without internal pressure and the slack plating will carry very considerable loads in the shear, although there will be shear wrinkles in the slack plating when the shear loads are high.

The remarks of Professor Prandtl on his observation of the ZMC-2, when the internal pressure was dropped to and below atmospheric, illustrate the behaviour of the plating under these conditions.

> * "Professor Dr. Ing. Prandtl reported from his own observation (at Lakehurst) on the smoothness and the freedom from wrinkles of the metal dirigible; even when air was expelled from the ballonets and the inside of the ship put under slight suction, no permanent wrinkles appeared, and the wonderful gas tightness was not affected."

* Quoted from "Zeitschrift fur Flugtechnik und Motorluftschiffahrt," December 29, 1930, page 630.

In the proposed large metaleads it is believed that the combination of structure and plating can be made to carry the required compressive loads better than in the ZMC-2 and that the ability of the plating to carry the shear loads without wrinkling, can be greatly increased. It is proposed in future designs to decrease the size of the unsupported panels of plating and this, along with the lesser curvature and thicker plating, will increase the shear strength.

The designers of the metalclad, therefore, believe that a system of combined structure and plating can be evolved which will carry safely all stresses arising when one cell is deflated and there is no internal pressure although it will be advisable to fly at reduced speeds under this condition, so as not to subject the ship to maximum aerodynamic loads.

The expression, as used by Professor Bairstow, for the meaning of the factor of safety of four is correct. The factor of safety of four is supposed to apply to steady straight flying conditions and static loads only. In case of extreme flying conditions, the factor of safety is calculated to correspond to the requirements as adopted by the U.S. Navy for the design of large airships which in the case of a deflated gas cell is specified as two.

In determining the safety factor of any member of the structure, the most unfavourable combination of loads is used in calculating the probable stress. In metalclad construction, for purposes of determining the longitudinal strength required to resist the bending moment, the factor of safety varies with the internal pressure. This, however, applies only to the longitudinal strength.

Mr. E. F. Spanner.—Pioneers in any new field of endeavour are always glad to receive corroborating evidence of the validity of their enterprise from allied professions. Hence, Mr. Spanner's reference, in which he quotes from a paper delivered before the British Institution of Naval Architects by Baron Rœnne, suggesting the use of an all metal skin for rigid airships, is very gratifying. Mr. Spanner's reference to the metalclad, making it appear to be a development of the semi-rigid, suggests the advisability of a new definition, namely, "pressure rigid" airships, which is rigid enough to maintain its shape at atmospheric internal pressure while at rest in the hangar or flying at slow speeds and relying on a slight internal pressure when flying at normal cruising speed or at top speeds.

In the United States Mr. Spanner has always been considered as an arch-critic of airships, but after meeting him face to face it is rather pleasing to observe that after all he appears quite open-minded on the subject and helpful in his suggestions.

Professor Jenkin.—Professor Jenkin calls attention to the typographical error in the preprint wherein the aluminium coating of alclad is defined as being .005in. to .007in. thick. The figures should be .0005in. to .0007in.

Replying to the question about the internal framework of the ZMC-2 metalclad, this structure is composed of twelve circular frames and twenty-four equally spaced longitudinal frames. In large metaleads it is contemplated that deep unwired transverse circular frames will be used and that the spacing between longitudinals may be to some extent reduced, thus adding to their number as the diameter increases.

Mr. Roxbee Cox.—It is very hard to answer Mr. Cox directly without going into the whole subject of variation of drag with scale effect, dependability of wind tunnel tests at various conditions of turbulence, etc. The choice of such a short fineness ratio for the ZMC-2 was dictated by weight considerations which in the case of this ship were dominating due to its very small size. Actually, the metal plating of the ZMC-2 is about twice as thick as it need be from a strength standpoint, but practical shop considerations prohibited the rolling of thinner sheets.

The discrepancy in the original wind tunnel tests is mentioned in answer to Mr. Bateman. Recently the results of tests in the British tunnel on a body similar to the ZMC-2 shape were published in Reports and Memoranda of Aeronautical Research Committee, and the lecturer would prefer Mr. Cox to make a

direct comparison with the R.101 if both models were tested in the same tunnel under the same conditions.

The lecturer admits that the ZMC-2 has a high drag coefficient, and emphasises again that the shape was chosen principally for weight reasons. The problem was how to obtain the greatest volume for the least area of a hull covering that is thicker than necessary.

Mr. N. S. Norway.—Mr. Norway in his discussion raised the question about maintenance of pressure in large metalclad airships. The lecturer anticipated that some questions about pressure control would be raised and therefore he included in the Appendix a paper by Mr. W. A. Klikoff which discusses this matter rather completely. He is sorry that the specific question as raised by Mr. Norway is not covered in sufficient detail in Mr. Klikoff's paper. It is proposed to design large metalclad airships to be able either to ascend or descend at the rate of 4,000 feet per minute under power. Descent without power, but with internal pressure is limited to 1,500 feet per minute, which will be used as a criterion for blower design. For a higher rate of descent under power with internal pressure, reliance is placed on scoops located on the hull. In case the high rate of descent should occur without power, then the stresses on the airship will be reduced, due to loss of forward speed and air will be supplied at atmospheric pressure as in conventional rigid airships. For smaller loads encountered in this case, the airship is considered to be amply strong at atmospheric pressure. Adequate emergency openings at the bottom of the hull to supply the air under atmospheric pressure for this condition will be provided.

In regard to deep transverse frames, the present proposed design of large metalclad airships contemplates their use. Undoubtedly the results of tests of the U.S. Navy ZRS-4 Zeppelin type will indicate if the proposed resilient diaphragm will be satisfactory for the purposes it is intended. The advantage of one type of frame versus another is still a controversial question between different engineers.

Concerning the weights, it should be admitted that metalclad airships are designed following the U.S. Navy requirements, which are considered ample from a strength standpoint, and that the British load system has not been used. This may add somewhat to the structural weight of the metalclad although it may happen that British requirements for worst loads may occur in such conditions when internal pressure can be more easily maintained than in conditions imposed by the U.S. Navy requirements, and therefore may be of lesser importance.

Captain Boothby.—Captain Boothby's historical reference to the prophecy of the late Commander Usborne, that eventually rigid airships will be metal covered, is indeed encouraging to us who have been wrestling with this problem for the past ten years without interruption.

It is quite likely true that hydrogen escaping from a small hole of a metalclad airship when ignited would burn like a gas jet and that if the flame were accessible it might perhaps be extinguished without any great difficulty. On the other hand, in the commercial application of airships one has the psychology of the public mind to deal with and although pure helium has only 92 per cent. of the lifting value of pure hydrogen, nevertheless it is the belief of the lecturer that the public will be willing to pay a greater tariff to compensate for this difference in lift, in order to obtain the additional increased safety which comes from freedom of fire hazard. Of course, the total elimination of danger of fire cannot come until heavy oil engines are substituted for petrol engines.

The metalclad ZMC-2 was inflated in two stages due to the difficulty of separating helium from air without going to the expense of installing a freezing process for this purpose. In the first stage cheap carbon dioxide was used to displace the air in the ship. The heavy carbon dioxide was let in at the bottom forcing the air out of the top of the hull. In the second stage the process was reversed. The light helium was forced in at the top while the carbon dioxide flowed out of the bottom of the hull. The carbon dioxide-helium mixture was

circulated through a caustic soda scrubber to remove the carbon dioxide and the purified helium was then admitted at a point ten feet above the bottom of the hull. Chemical control tests were conducted at five stations during the process of inflation to show the exact progress in the various parts of the ship, and to ascertain the purity of the gas. The entire operation of inflation is more fully described in "Transactions of A.S.M.E.," Aeronautic Division, 1929 (Aer-51-36), copy of which the lecturer will be glad to mail to Captain Boothby. Larger metalclads, having compartments, can be inflated with no more difficulty than conventional rigid airships.

The use of swivelling propellers for slowing down the forward speed of the airship or for checking its ascent or descent and to facilitate the blowing of air into the metalclad, all suggested by Captain Boothby, furnish an interesting opportunity for further investigation.

Mr. Duncanson.—In answering Mr. Duncanson about the variation of structural weight with size, it may be stated generally that comparing large airships of the same type and the same strength factor built so far, the structural weight of the hull should increase in proportion to the volume.

The greatest advantage in increasing the size comes in the reduction of horse-power required for the same speed. This reduces the relative weight of the engines and allows for an increase of load which can be utilised to increase the range of the pay-load capacity.

Mr. Duncanson's questions suggest reference to certain elementary differences between heavier-than-air and lighter-than-air craft. First, the airship is sustained by static forces and the airplane by dynamic forces. Second, the gross lift of the airship is determined by its volume, independent of its power plant, while the gross lift of the airplane is determined by its wing area and its power plant.

For example, in lighter-than-air craft the gross lift varies as the cube of the mean dimension, while the air resistance and the horse-power required vary as the square of the linear dimensions. In a heavier-than-air craft the gross lift is controlled by its aerofoil surface and its speed. It is evident that an increase in lift can be obtained more easily without a proportionate increase in weight by augmenting volume rather than by increasing area.

The result is that the useful or disposable load per horse-power of the airship increases very rapidly with volume, while in the airplane the useful load per horse-power is practically a constant, shows little increase with size, and actually decreases in extremely large sizes.

This explains why the airplane when applied commercially is essentially a short-range craft, whereas the airship is capable of negotiating long ranges and offers a real solution to the problem of trans-oceanic air transport.

Mr. Wyn Evans.—Mr. Evans' demand for higher speed for airships is well taken and is particularly applicable to the metalclad. It is the firm conviction of the lecturer that it is not desirable to operate large fabric airships at a speed of 100 miles an hour. On the other hand, this speed and even higher speeds present no difficulties to the metalclad design, but rather furnish an opportunity to prove the superiority of this type of construction over the conventional fabric type rigid.

Major Bumpus.—The complimentary remarks of Major Bumpus with reference to the ZMC-2 are most gratifying, particularly because they come from a leading designer of airplanes and flying boats. As a general rule heavier-than-air designers are none too liberal in their compliments to airship designers. Major Bumpus visited Detroit during the summer of 1929, when the ZMC-2 was nearing completion and therefore he is in an excellent position to qualify as a competent witness to testify with respect to the difficulties overcome in the accomplishment. As previously stated, these difficulties were magnified due to the smallness of the craft and gradually lose their importance as the size of future metalclads increases.

Mr. Bateman.—In answer to Mr. Bateman's question about the drag of the low fineness ratio hull of the ZMC-2, it can be said that the drag figures as originally published were based on variable density wind tunnel tests which have since proven to be erroneous due to interference of supports in the tunnel with the model. More recent check tests give drag values much higher. Results of tests run in a variable density tunnel on various fineness ratio hulls indicate that hulls with a fineness ratio of about 4 to 5 have the least drag. The question about factors of safety is covered in the answer to Professor Bairstow.

Mr. Wieser.—In answering the points covered by Mr. Wieser, (1) The question of fineness ratio is answered to Mr. Bateman.

(2) In the case of the ZMC-2, the thinnest available material for construction is governed by the thickness of the plating, although much thinner plating could have safely been used. Due to this weight handicap the shortest fineness ratio that was practicable was chosen.

(3) The fineness ratios contemplated for large metalclads will be larger, but it is considered necessary by designers to have the shape of sufficiently pronounced double curvature, therefore preferably the shortest possible fineness ratios are used. It happens that low fineness ratios contemplated seem to fall also into the least drag range. It is not proposed to use any parallel sections in large metalclads.

(4) The unbraced triangular transverse frames are incorporated in the new Goodyear-Zeppelin airship. Dr. Arnstein, the designer of the last mentioned airship, has indicated in a paper before the American Society of Mechanical Engineers* that with the increase of size the unbraced frames become lighter compared with wired frames, and the designers of large metalclad airships, so far as their studies indicate, are in agreement with his opinion.

(5) It should be realised that the largest percentage of metalclad airship weights consist of metal plating, gas compartment fabric and structural elements whose weights can easily be determined if backed by sufficient tests. The problem of airship analysis under different load conditions is fairly well standardised and therefore analysis of the structure and strength and weight of various members can readily be computed. All the weights of other items pertaining either to metalclad or conventional Zeppelin airships have been taken for known weights of present rigid airships. Therefore, it should be realised that the weight study, as given in the paper, is not too optimistic; is not based on mere guess work; and that a large tolerance for possible overweight is included. As a matter of fact the designers were always trying to be conservative in their estimation of weights. It is hardly fair to suggest that any present weight estimate of a large metalclad can represent only a " rough approximation " when it is based on ten years' uninterrupted, continuous, thorough, scientific investigation. It can be added, as a matter of proof of accuracy, that the ZMC-2 when finally delivered to the U.S. Navy had a useful load of 127lbs. in excess of the contract specifications, and that these specifications were based on weight estimates prepared prior to the completion of detailed shop drawings.

(6) In answer to the quoted statement of the late Colonel Richmond, it should be understood that in large metalclad airships the structure is designed in such a manner that it acts in common with the plating as the strength member, similar to steamship construction. It is very regrettable, but the lecturer cannot check the comparative figures as given in the late Colonel Richmond's paper, and assumes that there must have been an error either in print or in estimation of the plating, or that Colonel Richmond did not include all of the items he listed as corresponding to a weight of 1/200in. duralumin plating. As a result of a study of comparative weights, the metalclad airship designers may state that if all the items of conventional rigid airships are considered, which are replaced in the metalclad type by plating and internal framework, the metalclad

* Trans. A.S.M.E. January-April, 1928, AER-6.

airship of large size is not handicapped from a weight standpoint. The average thickness of the plating on a metalclad airship of 5,000,000 cu. ft. would be about .015in.

(7) The wind tunnel tests made by the designers of large metalclad airships have so far indicated that increase of drag due to roundness of the stern is negligible, provided no abrupt changes in curvature are made. Although the air flow may be somewhat less smooth, the skin friction drag of a pointed stern is eliminated.

Wing Commander T. R. Cave-Browne-Cave.—Commander Cave-Browne-Cave's contention that in large metalclads the distending pressure at the bow and stern would become magnified when pitched, would be true if there were no transverse diaphragms which tend to relieve such excess pressure.

His suggestion that a metal airship might be inflated initially with an internal pressure of one pound per square inch, resulting in greater simplicity in the operation of the ship, has fascinating possibilities but for the fact that this increased pressure would necessitate a considerable increase in the thickness of the hull plating, thus adding excessively to the dead weight of the ship.

The Commander brings up the question of the advisability of the use of helium from an operating standpoint, citing the fact that perhaps the average airship commander would prefer the use of hydrogen and thus gain an increased lift which could be utilised for additional fuel load, thus adding to the cruising range of the airship. The designers of the metalclad airship in estimating its commercial performance when inflated with helium have always insisted that in its application to any particular commercial route it should carry a 50 per cent. fuel reserve, which reserve it is believed corresponds with ordinary steamship practice. It is unfair both to the designers and to the general public to advertise a commercial range of an airship that does not contemplate such a reserve. And certainly no airship captain would fear the loss of a ship on any particularly specified route when he has 50 per cent. reserve of fuel available.

In other words, it is high time that common sense considerations be the rule rather than the exception in so far as estimating the performance of aircraft in trans-oceanic travel is concerned. So far, every airplane that has flown the Atlantic Ocean has been nothing more than a flying gas tank, overloaded with fuel and depending on good luck and good weather rather than on an adequate fuel reserve to enable it to accomplish its voyage. Pay load in each instance has equalled zero. So far no performance of any trans-Atlantic airplane has offered any inducement so far as safety is concerned that could persuade the general public to patronise any such service. So it is repeated again, that an airship regardless of the type of gas used for its inflation, should carry a fuel reserve of 50 per cent., thus enabling it to compete with adverse weather conditions and bring its cargo and passengers into port safely. In fact, it is believed insurance companies will refuse to undertake an insurance risk on a commercial airship or on its cargo and passengers when the fuel reserve falls below this figure.

Mr. John L. Hodgson.—Mr. Hodgson raises a number of interesting questions.

(1) If the rivets were dome shaped instead of flat they might be slightly stronger, but they would not be any more effective in so far as making the seams gas-tight is concerned, for one relies entirely on the sealing compound which, through capillary action completely fills all the voids between the overlapping sheets. So far as abrasion of the gas-bags by the rivets is concerned, in the ZMC-2 final coats of the sealing compound were applied to the interior of the riveted seam in such amount as practically to submerge the rivet heads within the compound itself, thus producing a faired smooth surface. It is believed that the advantages of making the rivets dome-shaped would not compensate for the complications necessary to produce them.

(2) The only reason the lecturer knows for not mixing hydrogen with helium to increase the lift is the complication of repurifying the helium when hydrogen is present. Furthermore, the percentage of hydrogen injected in the helium would have to be quite low (probably less than 20 per cent.) if the fire hazard were entirely eliminated.

(3) It is proposed to make the gas-bags of rubberised fabric of a quality which shows considerable improvement over that used in the ZMC-2. We have no data as to the permeability of fabric when used as a container for a mixture of hydrogen and helium, but it is believed that it would be slightly higher than with helium alone, the increase of permeability depending entirely upon the percentage of hydrogen used.

(4) The eight-fin group as used in the ZMC-2 is based on the fact that the conventional four-fin arrangement does not utilise all the air passing around the hull for stabilising and control purposes. By introducing multiple fins, higher aspect ratios are possible and consequently higher efficiencies than in the conventional low aspect ratio fins, provided they are properly spread around the hull so as not to cause too much interference. The multiple fin group somewhat approaches the biplane principle in airplanes. The advantages of the eight-fin group have been proven by wind tunnel tests.

(5) Bow elevators have often been suggested for use on airships, but the question of their usefulness for control will undoubtedly be balanced by increase in drag and to what extent one will counterbalance the other is not definitely known.

With respect to the commercial application of the airship, Mr. Hodgson ignores the fact that in this "work-a-day world" one must find an economic usefulness for a new mechanical device if he is to succeed in securing the necessary finances to prosecute its development.

In the complexity of modern life it is impossible to produce even such a universal device as the telephone without employing the use of 20 different materials imported from 26 different countries. This is one of the multitude of examples that might be cited which necessitate cultivation of foreign markets and foreign sources of supply.

We live in a day when world states must plan to "live and help live," and it is believed the airship is destined to become a symbol of international co-operation that will finally bring about the fruition of this ideal.

Mr. T. S. D. Collins.—Mr. Collins raised some criticisms about the strength of the airship which were also raised by Mr. Norway and answered in replying to his questions. Mr. Norway himself answered them somewhat in making a comparison of the M.C.50 and R.100 from the standpoint of the two design procedures. It should be realised that each and every design has certain limitations and although the British requirements specify that sufficient dynamic lift should be obtained to balance the loss of gas caused by bursting of a single cell, the Court of Inquiry of the R.101 disaster had to analyse the condition of trimming with two cells deflated. It appears that even this condition should have been considered and points to the fact that limitations occur in any design. Flooding of several compartments on a steamship may cause its loss if no steps are taken to combat it; the same comparison applies to a large metalclad airship which may have two alternatives in case of punctured cell or hull, depending on the nature and size of the puncture. The ship may be either slowed down to repair the damage or proceed at slow speed to its home port at atmospheric internal pressure. Or the ship may be speeded up with all the scoops open, thus providing enough air to maintain the desired pressure and compensating for leakage through the punctured hole.

But let us speculate for a moment on the circumstances that might actually produce a large puncture in the metal covering of a metalclad airship. Except in war time it is submitted such a puncture would arise only from four sources:—

(*a*) In manœuvring an airship in and out of a hangar, in which case neither human life nor the integrity of the ship itself would be endangered, inasmuch as its "dry-dock" could be immediately utilised for repairs.

(*b*) In the event of collision of one metalclad with another metalclad airship which, according to the law of probabilities, should certainly be more remote than a collision between two ocean liners.

(*c*) In case a propeller should fly off its hub, which certainly would endanger the airship to no greater extent than if the same accident should happen to a propeller on an airplane. Furthermore, a bursting propeller would certainly do more damage to a fabric-covered airship than to a metal-covered airship.

(*d*) In case some crazy airplane pilot engaged in unlawful acrobatics in the neighbourhood of a metalclad should accidentally dive into its hull.

In so far as war-time punctures are concerned, due to shrapnel, bombs, machine-gun bullets, etc., these are to be expected and must be accepted philosophically as part of the consequences of warfare itself against which no provision can be made.

It is further emphasised that the danger of a puncture or bursting air chamber in the metalclad airship is eminently less than in an airship equipped with delicately thin fabric cells. In other words, if the future of commercial airships hold no greater promise than enclosing its precious buoyant gas in perishable fabric little thicker than a lady's pocket handkerchief or hardly more durable than a tea napkin, then those engaged in such an enterprise had better give up the art and find other employment. Certainly the memory of man must be short if it does not recall the contributory influence of fabric to the wrecks of the Shenandoah and R.101, and the near disasters to the Graf Zeppelin and R.100 on their respective initial flights westward across the Atlantic.

It may be again repeated that every structure has certain limitations and the metalclad airship is not exempt from this general rule. The designers have tried to anticipate the most severe conditions possible and have tried to provide means of combating them. Evidently Mr. Collins has misunderstood the diaphragms to be used to separate the gas chambers. These will not be made of fabric alone, but will be laced to resilient wires to support the fabric, similar to those adopted on the ZRS-4.

The weight comparison of the metal cover of the ZMC-2 with the R.100 is not very fair, because the ZMC-2 plating was made of the least thickness of metal obtainable, which made the plating over-strong for the pressures used. The whole question of static and dynamic trimming of the large ship has been gone into thoroughly and no particular difficulties have been encountered so far.

The question of superheating has not been overlooked by the metalclad airship designers. It may be stated unofficially that the U.S. Navy is conducting tests to determine the effect of superheat on the ZMC-2, and so far no excessive values have been obtained. The air space between the outer cover and gas-bags may be extremely dangerous if Dr. Eckener's testimony before the Court of Inquiry of the R.101 disaster is recalled, when he pointed out that gas escaping from cells may have contributed to the uncontrollable inclination of the R.101.

The author agrees with Mr. Collins that wire is the most efficient structural member from a weight standpoint. But it should not be overlooked that each tension load in a wire calls for a girder to take a compressive load produced by it. Although from a weight standpoint a wire is a most efficient member, from an operating standpoint it is very inefficient because of the great amount of attention required to insure that each wire has its proper tension or load. The metalclad airship tends to reduce the cost of operation and maintenance and therefore the designers have tried to eliminate all the wires they could.

The use of hydrogen for airship operation is very desirable from a lift standpoint, but admittedly dangerous. Witness the greater percentage of

people killed in disasters of the Roma, R.38 and R.101 as compared with the wreck of the Shenandoah, which was inflated with helium.

Mr. H. E. Wimperis.—Mr. Wimperis very properly brings up the cost of importing helium into England for commercial airship purposes. It is believed this cost has not only been exaggerated, but that it can be proven it does not exist. For example, it is reported that Dr. Eckener proposes to inflate his new trans-Atlantic commercial Zeppelin with hydrogen at Friedrichshafen for its initial trans-Atlantic flight, continuing on to Fort Worth, Texas, where in the immediate neighbourhood of the helium refinery, cell after cell will be deflated and in turn re-inflated with helium. Inasmuch as he will carry a commercial load across the Atlantic on its first trip, his only expense for transporting helium back to Germany will be the initial cost of his hydrogen, about $2 per thousand cubic feet, plus the fuel on the journey from the eastern seaboard of the United States of Texas. Unquestionably there will be sufficient passengers available in the States who desire to make the Texas trip to make even this journey a self-supporting proposition.

Furthermore, Dr. Eckener plans on each successive return trip to Friedrichshafen to pump out of his airship 9,000 cubic metres of helium gas which will be stored in suitable gasometers for future use. This plan he can pursue without subtracting from his commercial payload westbound due to the difference in altitude between the Atlantic seaboard base in the United States and the altitude at Friedrichshafen, Germany. Naturally, upon returning to his seaboard base in the United States this 9,000 cubic metres of helium must be replaced without negotiating an additional voyage to Texas. This will necessitate the transportation of helium via rail from Texas to the Atlantic seaboard, which cost, using the new helium tank cars designed for this purpose, has now been reduced from $30 per thousand cubic feet to about $10 per thousand cubic feet.

If our English cousins desire to pursue a similar plan in the future, unquestionably they would be welcomed with the same whole-hearted co-operation that has been promised Dr. Eckener.

In conclusion, it should be emphasised again that any monopoly of helium which the United States at present might enjoy is limited only to production and not to source of supply. No one would dispute the fact that when the demand justifies the cost of exploration, helium deposits will be located in the old world as well as in the new world, and in ample volume to satisfy the needs of all. And furthermore it should not be overlooked that as the demand increases, resulting in an increased volume of production, the cost of refining decreases proportionately. This has been true of every new raw material, which, when first discovered was looked upon as laboratory curiosity, but when applied commercially soon became available at a price within reach of all having use for its employment.

Mr. Wimperis and other members of the Royal Aeronautical Society who have participated in the discussion have been most cordial in their reception of this lecture on the metalclad airship, and on behalf of his associates the lecturer desires to express his appreciation of the interest displayed, and feels that his delightful visit to England has been well worth while if in a small measure it may contribute toward the future development of airships in this wonderful country.

REVIEWS

The Airplane

Frederick Bedell, Ph.D. and Theodore E. Thompson, M.E. Macmillan & Co., 1931. 16/- net.

This is a new edition, very much enlarged, revised and added to of Dr. Bedell's earlier book under the same title first published in 1920. In the first chapter on sustentation Fig. 4a showing lift on an aeroplane has the remarkable caption "lift is inclined when machine is inclined." The book is very largely an elementary exposition of the principles of flight and performance and like many books of a similar nature, falls between two stools. It is too advanced for those who know nothing about aviation and too elementary for those who do. The authors do not appear to have had any particular class of individual in view when preparing their book and have tried, too, to put a quart in a pint pot. In the chapter on special types of heavier-than-air craft it is stated that several flights have been made with the helicogyre in England. The wish is perhaps father to the thought.

Wings of To-morrow. The Story of the Autogiro

Juan de la Cierva and Don Rose Brewer. Warren and Putnam. $2.50.

I recommend every designer of aircraft to read this book; I recommend the officials of Imperial Airways to read it before the officials of other air organisations do, particularly chapters 14, 15, 16 and 17; I recommend every man in the street who wants to fly to read it; and I recommend everyone who has been brought up in the rigidity of pure mathematics or civil engineering to study it. They'll all benefit from the Wings of To-morrow.

This is a story of persistence and ingenuity which can only be a pure inspiration for present-day youth which is entering the air age. The birth of the first flying machine, the development of that machine, the immense, almost unbelievable progress which has been made in aviation, have all come in the span of a young man's lifetime. The Wright Brothers opened up a new road of progress and that road has been trodden with increasing speed. But it is only one road. Senor de la Cierva has laid down the foundation of another aerial road, and the reviewer confidently predicts that the road will lead farther and to a wider aerial prospect than the original road.

The Wings of To-morrow is not merely the story of the inception and development of the Autogiro by its inventor. It is the unfolding of a very remarkable mind, not the least of those which have been nurtured on Spanish soil.

A Register of Civilian Aircraft

W. O. Manning and R. L. Preston. Sir Isaac Pitman & Sons, Ltd. 2s. 6d. net.

This register, which gives the names and addresses of the owners of all civilian aircraft registered in Great Britain and the registration letters of the aircraft, will, if its publication is continued, grow very rapidly into a thick volume. There is no question of the usefulness of the present slim volume. From it one at once learns that the owners of the largest number of aircraft are National Flying Services, Ltd. (47), Imperial Airways, Ltd. (37), and the De Havilland Aircraft Co., Ltd. (32). It is interesting to note the increasing use which is being made by business lines of aircraft, a considerable number of whom are shown by the index to possess their own machines.

Cross Country Flying

Major Oliver Stewart. Constable & Co. 6/- net.

From Major Stewart one expects a readable book and Cross Country Flying fulfils expectations. In the book Major Stewart abolishes the bogey of abstruse mathematical calculations and shows that, for the ordinary pilot, finding one's way across country presents very few difficulties. And the simpler flying becomes, the more popular it will become. Tell the world it cannot fly across country without being a first class navigator and the world will refuse to fly. Make it as easy as touring in a motor-car and the air will become the world's highway. Major Stewart explains in simple language the uses of the *necessary* instruments, the compass, air speed indicator, the bubble, turn and drift indicators and the like, and maps and map reading. There is nothing complicated here, nothing beyond the intelligence of the average individual. To this book Major Stewart adds a useful chapter on preparing for a cross-country flight, one on a typical flight and a third on bad weather flying. Chapters on those regulations under the Air Navigation Act referring to cross-country flying and on meteorology complete a book which every light aeroplane owner will find of the greatest assistance.

The Air Annual of the British Empire, 1931-32

Gale & Polden. 21/- net.

This is the third annual issue of the Air Annual, which has now become firmly established. This issue has broken away from its predecessors in a number of ways wholly to its advantage. Perhaps the most important is the introduction of French and Spanish sections which will enable others to realise to the full the value of British aircraft and the progress which is being made. The size of the annual has been increased and so the too great bulking of the book with the increase in contents has been avoided.

As with preceding volumes the Annual not only contains vital statistics and information on British aircraft and aircraft operations, but a number of articles of great use. Among the well-known writers appear The Master of Sempill, on Sea-going Aircraft, Captain M. Hotine, on Air Survey, Captain C. H. Latimer Needham, on Soaring Flight, Major Oliver Stewart, on Military Aircraft, Mr. H. O. Short, on Marine Aircraft, and Major E. P. Bulman on British Engine Development.

A most useful article is that by Mr. A. E. Russell giving a comparison between aircraft structural strength requirements of Great Britain and other countries, a matter of considerable importance and one to which more attention is, and must be paid as air communications increase.

The Air Annual is one of the best reference books of its kind. As the publishers fear it bulking still further in the future it seems a pity to waste space printing extensive photogravure plates which could just as well be incorporated in the text. One is glad to see a single comprehensive index has taken the place of the sectional index of previous years.

Power and the Internal Combustion Engine

W. E. Dalby, F.R.S. Edward Arnold & Co. 18/- net.

Professor Dalby is the London University professor of engineering at the City and Guilds Engineering College and has had a long experience. He has seen the development of the Internal Combustion Engine in all its stages, seen the rapid alterations in design which make a book dealing largely with specific engines become quickly out of date.

Professor Dalby confines his book chiefly to common principles and takes for granted knowledge of the general action of the Internal Combustion Engine. Chapters 1 and 2 cover gases and fuels, their characteristics and combustion,

chapters 3 and 4, Performance, chapter 5, the Suction Gas Plant, chapter 6, the Petrol Engine, and chapter 7, Heat Flow and its effect on design. There is little in the book about the compression-ignition engine and recent developments. The book is a valuable one for students, if read in conjunction with those covering specific engines in more detail, and contains much useful information not always available in many books on engines.

International Air Guide

Imprimerie Crété, Paris. £1 15s. 0d.

This is the first issue of The International Air Guide. The text is in English, French and German. The book is monumental both in its actual size and scope, and if the present state of aviation enables such a book now to be published one visualizes in a few years' time each annual issue being the size of a modern ten-volume encyclopedia.

The International Air Guide is designed to give every information about air transport. In their task the publishers have had the co-operation of the League of Nations, the International Air Traffic Association, Air Ministries and Post Offices, the International Commission of Air Navigation and other important organisations.

The Guide gives particulars of air routes and the companies operating them, luggage, freight and air mail particulars, customs and insurance. A section is devoted to the private owner, giving him full particulars of the regulations in different countries, flying schools, etc. The private owner is given particulars of meteorological services available, aerodromes and prohibited areas. A most valuable section is devoted to air route maps in detail

The Guide is a most comprehensive volume of information of use to all air travellers in Europe, but its information for other countries is scanty or non-existent. It would be difficult if not impossible to provide similar information for America, for example. There appears to be no information about Russia, and touring facilities there and in Spain seem non-existent.

The chief fault to be found in this really valuable book is in its actual arrangement. Advertisements are mixed up with text in a most irritating way, making information difficult to find. Much information is, as must be expected, heavily condensed and is uneven. Under the heading of Associations in Great Britain, for example, appears no mention of the Guild of Air Pilots and Navigators, nor of the British Gliding Association. The list of Light Aeroplane Clubs, too is incomplete, and information about periodicals and papers published in various countries wants adding to. One looks, however, on the first edition as an experimental effort, and one which will be improved upon, and minor criticisms have been purposely avoided. As an experiment it holds out considerable hopes. That such a book could have been produced at the present time is significant of the progress which has been made in aviation. It should be in every big business office.